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A STUDY TO EVALUATE THE POTENTIAL OF CATTAIL AS AN ENERGY CROP

by

G. Lakshman

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ABSTRACT

There is a need to develop renewable energy sources which can replace or supplement conventional fossil-derived fuels in agriculture, transportation, homes and industries. It is, however, important to develop such sources without creating food-feed-energy conflicts in the land utilization in the agricultural sector. Recent studies in the United States, particularly the recent assessment conducted by the Solar Energy Research Institute, have shown that emergent aquatic plants are particularly well suited as significant sources of ethanol and solid fuel. One such emergent aquatic plant is the Cattail which shows great promise as a competitive energy crop under Canadian conditions. Cattail, a perennial and rhizomatous plant, is indigenous to most parts of the world and is an abundant species in the aquatic environment.

The potential merits of cattail as an energy crop for the production of ethanol and also solid fuel are examined in this report along the following lines.

Land Base

A very large and untapped land base exists in all areas of Canada for the managed cultivation of cattails. These comprise the wetlands, peatlands, saline lands and agriculturally marginal lands, where suitable land areas can be hydrologically managed to produce cattail crops. The total land base not presently used for agriculture is anywhere between 780,000 km^2 and 5,300,000 km^2 in Canada.

Productivity

Cattail's annual productivity can exceed 40 tonnes per hectare of dry matter under managed cultivation. Possibility exists to increase

this through multiple above-ground harvests and agronomical enhancement of primary production. This compares very favourably with the productivities obtainable from conventional crops such as wheat (1.3 to 7.0 t/ha), Jerusalem Artichoke (17 t/ha), Sugarbeet (30 t/ha) and Corn (7 t/ha).

Cattail is a very efficient C_3 plant with high leaf-area-index (up to 18) and photosynthetic efficiency (up to 13.6%). It has a wide tolerance for salinity levels and pH variations. Cattail does not seem to have any pests or diseases which can stifle its growth. Cattail stands can be established in freshwater as well as in nutrient rich environments. A major advantage is its ability to grow without any annual fertilization in standing water (up to 0.5 m depth) or in moist soil.

Carbohydrate Distribution

Cattail produces essentially two types of feedstocks; the above-ground portion which consists of cellulose and hemicellulose and the below-ground portion which consists of starch, reducing sugars and some cellulose. The leaves contain about 30 to 35% cellulose and 19 to 37% hemicellulose. The lignin content varies between 10 and 15%. The rhizomes contain over 35% starch and about 25% sugars. Over 40% of the total biomass can be converted to fermentable material.

The starch and sugar contents in the rhizome vary with the growing season and reach the maximum levels towards the end of the growing season.

Harvesting and Material Preparation

There are several reed harvesters manufactured by the Seiga Harvester Company of Denmark which have been used in Europe and the U.S. to remove aquatic and terrestrial weeds and reeds. These have been successfully used to harvest cattails from marshes in several field studies. Modified

potato pickers have been used to harvest cattails grown in peatlands in the northern Minnesota locations. Both the leaves and the rhizomes have been harvested using these machines.

However, development of a machine to harvest cattails, leaves and rhizomes, under Canadian conditions should be encouraged.

Ethanol Production

Extrapolation of the available data on the process costs for wheat and aspen to the case of cattails gives the cost of ethanol production to be about $0.48 per litre. This does not include the pay-back credits from the sale of protein-rich residue after fermentation as an animal feed. Laboratory studies on pretreatment and conversion can very well produce more efficient processes specifically designed for the cattail biomass which can significantly reduce the ethanol production costs. Yields ranging from 1,500 litres to 6,000 litres of ethanol per hectare are possible under the current production scenarios using the wheat/aspen processing technology.

Solid Fuel Production

Pelletized fuel from cattail can be produced to obtain more than 19 MJ/t by direct combustion. Its commercial exploitation for home heating and grain-drying should be seriously investigated.

It is proposed that cattail should be seriously considered as a viable energy crop to produce ethanol and solid fuel. Recommendations for future research are outlined.

THE ENERGY SITUATION

The energy crisis brought about by OPEC in 1973 prompted an immediate critical appraisal of the energy situation in terms of supplies and demands in all industrialized countries and many of the third world nations. And Canada, despite its impressive resource base and small population, was not immune to the global energy crisis. Canada, on a per capita basis, fares extremely well in terms of the energy resources compared with the world figures as shown in Table 1.

TABLE 1

SOME OF CANADA'S ENERGY RESOURCES
(Ref 29)

Source	"in place" X 10^9	Exajoules	per capita CANADA	per capita WORLD	
Oil	200** barrels	1,200	8,700	460	barrels
Coal	140 tonnes	4,000	6,100	2,500	tonnes
Natural Gas	220 MCF	230	9,500	2,500	MCF
Forests	7 tonnes	140	300	31	tonnes
Crops(per year)	0.04 tonnes	0.6	2	0.2	tonnes
Municipal wastes per year	17 kg	0.2	740	350	kg
Sunlight	2.3 MW	35,700	50	7	MW
Hydro	73 Watts	2.3	3,200	2,700	Watts
Uranium	1 Kg	181	40	1	Kg

** includes the oil sands and estimates on frontier oil.

But the high concentration of these resources in the West and the large expanse of the country generating transportation and delivery over-costs have resulted in Canada having a surplus of energy in one part while the other part having to import foreign oil to meet its demand. Severe climatic conditions, the high standard of living that the population enjoys and the increasing energy demand from the industrial sector have made Canadians one of the highest per capita energy consumers in the world as shown in Table 1. In the energy picture the conventional energy sources such as petroleum and natural gas satisfy about 62% of the total primary energy requirement. Table 2 provides the summary of the supply potential from various energy sources.

TABLE 2

SOURCES OF PRIMARY ENERGY - 1977
(Ref 29)

Primary Energy Resources	% Share
Coal	8.6
Petroleum	43.8
Natural Gas	18.2
Biomass	2.9
Nuclear	2.9
Hydroelectric	23.6

The National Energy Board's (NEC) analysis of the energy supply-demand situation in Canada projects an average annual growth rate of 2.3% for the primary energy demand to the end of the century from the current levels.

As a comparison, the demand for 'Other Renewable Energies' which includes the energies derived from biomass, agricultural and forest residues is expected to achieve a growth rate of over 19% on an annual basis, from 1980 to 2000. Table 3 shows similar projections for other sources of energy.

TABLE 3

NEB FORECAST OF PRIMARY ENERGY DEMAND - CANADA
(Petajoules)

NEB	1980	1985	1990	1995	2000	AAI-% 1980-2000
Natural Gas[1]	1 819.7	2 424.8	2 799.4	3 089.6	3 545.4	3.4
Crude Oil[2]	4 068.3	3 893.9	3 757.3	3 904.1	4 251.2	0.2
LPG[3]	28.5	38.8	93.3	141.1	149.6	8.6
Hog Fuel & Pulping Liquor	317.9	380.6	447.9	506.7	568.4	2.9
Other Renewables	7.6	9.5	87.4	164.3	266.6	19.5
Coal	1 017.8	1 144.0	1 335.5	1 710.9	2 051.4	3.6
Hydro	2 660.2	3 044.2	3 355.7	3 514.5	3 927.2	2.0
Nuclear	436.1	851.9	982.0	1 058.1	1 415.7	6.1
Total Primary Energy	10 356.1	11 786.7	12 858.6	14 089.3	16 175.6	2.3

[1] Includes ethane
[2] Includes refinery LPG
[3] Includes gas plant LPG only
AAI—Average Annual Increase

Figure 1 shows the comparison of forecasts for 'Other Renewable Energy' demand during this century. Using the middle demand and base supply potentials and considering only the crude oil and equivalent sources, it is estimated that the total imports will increase at an annual growth rate of over 10% for the period 1980 to 2000.

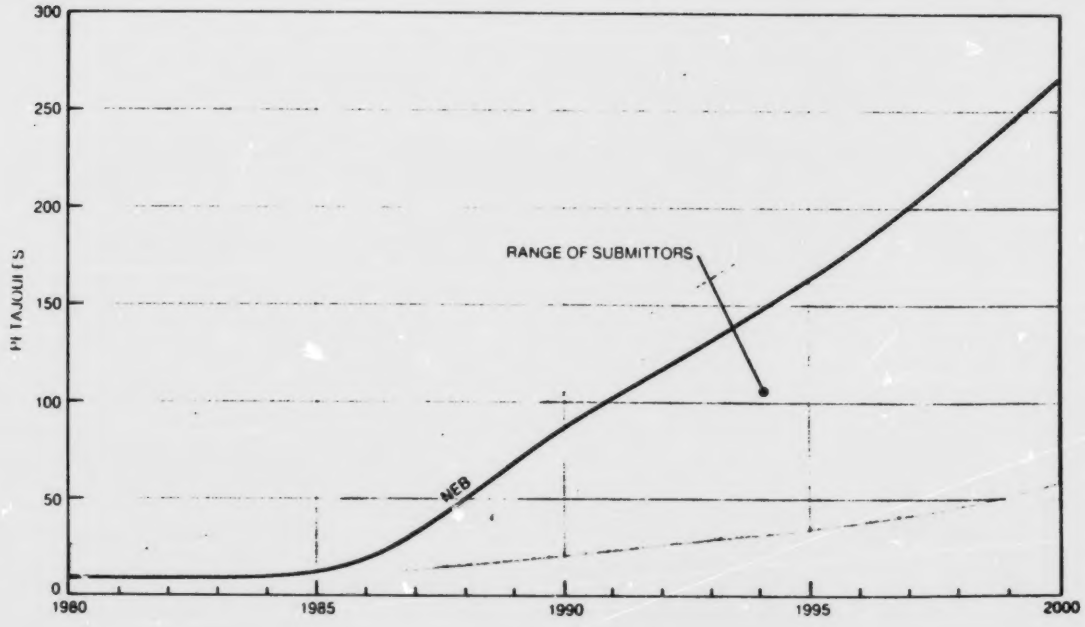


Fig.1 National Energy Board's Forecast for Other Renewable Energy Demand till the End of the Century. (Ref 29)

Table 4 gives the estimated quantities in terms of middle and base supplies.

TABLE 4

SUPPLY/DEMAND BALANCE FOR CRUDE OIL AND EQUIVALENT
Middle Demand versus Base Supply
($10^3 m^3/d$)

	1980	1985	1990	1995	2000
Production	245	192	179	157	123
Requirements	300	287	271	280	306
Net Imports	55	95	92	123	183
Exports[1]	15	7	3	0	0
Total Imports	70	102	95	123	183

[1] Heavy crude oil estimated to be surplus to domestic requirements in Montreal and West.

Hence, this staggering reality demands that the energy question be resolved through a comprehensive examination of the options available at present and those that can be developed through innovative approaches. It is a question which requires the most urgent solutions if we are to reduce the vulnerability of the nation's economy to drastic oil shortages.

The energy equation has several terms - conservation, efficiency of utilization, and the development of new resources - all of which determine to varying degrees the shape of the energy situation. Canadian efforts to address all of these issues have sought to identify the renewable resources such as the biomass as the area which deserves serious consideration. The potential of biomass production in Canada is admittedly very large. Our large forest industries, agricultural and livestock operations, municipal solid wastes, and the conventional food crops diverted for energy use are all expected to play a significant role in the national strategy designed to establish a dependable renewable energy base. A Government of Canada goal is to have 10% of the nation's primary energy supply from renewable energy sources based on the biomass by the year 2000. The bioenergy contribution to national energy needs is predicted to double from the present share of about 3.5% by the end of this decade, and perhaps triple by the end of this century. This means that within 20 years, the bioenergy can provide about 1 Quad (1 EJ/y) in primary supplies. This is expected to be achieved by utilizing the marginal benefits available from the forest and farm residues in Canada.

However, this approach is beset with some very definite problems. There are problems related to consolidating the forest and farm residues

either at the energy producing site (for example, producing ethanol or methanol) or at a convenient location from which they would have to be transported to the energy producing site. We need cost effective operations for harvesting, densifying and drying the biomass throughout the year. The final product value may not be high enough to justify the energy and cost input into these processes. Canada can produce only limited quantities of ethanol through the fermentation of low-value sugar or starch feedstocks. They are economically viable only under high oil costs (Juneja et al, 1980). The other alternative is to utilize corn and feed grains which can yield larger quantities of ethanol. This approach cannot, however, be justified because;

. High costs of the valuable agricultural land make it very expensive,

. It will upset the food-feed system and will produce unfavourable impact on the agricultural operations,

. There will always be a management problem because the best economic use of a given agricultural land will depend upon the comparative international prices for grain and oil; this is sure to create confusion among farmers in general and produce uncertainty in the future of those who are committed to the grains-for-energy programs.

and . Rising cost of fertilizers and energy will adversely affect the economics of ethanol-from-grains projects.

There is a second generation bioenergy potential which is being actively investigated by several European countries and the U.S.A. It is the vast untapped potential of reeds and marsh plants which can be cultivated in lands unfit for agricultural production. This approach

makes a lot of economic sense as it is based on'utilizing' the hitherto unused 'waste lands' such as agriculturally marginal lands, peat lands, moderately saline and flooded soils, and wetlands, leaving the valuable agricultural lands for food and feed production.

This concept has the following advantages:

. It encourages maximum utilization of land areas which have been entirely neglected through decades of development in agriculture and land use,

. Cultivation of reeds and marsh plants in these areas can help to solve many of the hydrologic and soil problems. Marsh plant cultivations significantly increase the fiber and organic content of these soils, and will, over the years, improve their capability to produce economic crops. The surplus water in flooded soils will be allowed to be lost rapidly to the atmosphere by large evapotranspiration rates in the marsh plants.

. This concept of managed cultivation of marsh plants to achieve maximum productivities forms the forefront of wasteland utilization efforts to produce viable economies out of agriculturally uneconomical and unuseable lands.

It has the potential to generate industries and resources with a very low land cost.

This report takes up the question of the 'second-generation' bioenergy crop. Cattail has been identified as the most promising marsh plant which can play a significant role as an energy crop in the North American context.

The following sections examine the problems and prospects of cattail as a viable option.

To summarize:

. Although Canada has vast energy resources and enjoys one of the highest per capita energy supplies in the world, an oil shortage or an increase in world prices will invariably affect its economy.

. NEB (National Energy Board) predicts an average annual growth rate of 2.3% for the primary energy demand to the end of the century from the current levels.

. The demand for 'Other Renewable Resources' which includes the demand for energies derived from biomass, agricultural and forest residues is expected to increase at an annual growth rate of over 19% from 1980 to 2000.

. Total imports of crude oil and equivalents will increase at an annual growth rate of over 10%, during the period 1980 to 2000.

THE WETLAND OPTION

The philosophy underlying the development of biofuels is not to fill the gap created by the depletion of fossil fuels in the transportation and gas pipeline sectors. The biofuels will, however, play an important role in the mix of future energy sources (Benemann, J.R. 1978). It is rather to develop the bioenergy potential in specific areas of energy demand where it can effectively and efficiently substitute for the fossil fuels, and to assign the energy from biomass a viable role in the nation's energy equation. It contends that fossil fuel reserves are, by nature, concentrated and after production the petroleum or the natural gas has to be transported over large distances to the user-sites which adds significantly to the delivery costs. Biofuels which are produced at least under optimum conditions, at sites where biomass is available, can be geared to displace fossil fuels with minimum economic penalties.

It is understood from what has been shown in the previous section that if the use of biofuels is streamlined to displace a part of the primary demand for conventional energy specifically in terms of petroleum and natural gas, the energy picture will look more optimistic and stable. It is important to recognise that Canada's resources of good agricultural land are limited and that the lands that are currently devoted for agriculture should be maintained so with adequate measures against degradation of soil and depletion of nutrients. It is necessary to maintain this base solely for agriculture, and explore ways of putting agriculturally 'unuseable' lands for raising energy crops. Well over half of Canada's land resource is wildland; only 120 million hectares, about 13% of the

country's land area, are defined as potential agricultural land, and include 60% suitable for field crops and about 40% suitable only for pasture. (Nowland and McKeague, 1977).

Tables 5 and 6 show the proportion of land areas in each province which falls into various CLI (Canada Land Inventory) categories and the percentage of total area that is classified as good agricultural land. The classification of lands refers to various limitations imposed on the lands for crop production and categorizes lands into seven groups. Agricultural capability classes 1-3 can support crop production and are free from severe physical limitations. Classes 4-5 can also support economically viable agricultural production, although class 5 is recommended only for perennial forage crops or improved pasture, and class 4 has limitations that either restrict the range of crops or require special conservation methods, or both. Classes 6 and 7 are unsuitable for grazing and agriculture, respectively.

It has been argued that exploiting the vast land base available as wetlands, peatlands and marginal lands for producing energy crops would relieve the pressure on the valuable food grains and feed crops, and prevent conflicts in the agricultural industry. This approach has been seen as a motivation for putting the 'unuseable' lands into active production. It is, therefore, necessary to assess the extent of this resource base that can be tapped in Canada.

Recently the Aquatic Species Program (ASP) was established by the United States Government to implement a plan to develop, demonstrate, and commercialize aquatic biomass energy systems for maximum contribution to the U.S. energy supplies. The ASP has estimated that the total U.S.

TABLE 5

Areas in Soil Capability Classes by Regions and by Provinces

(thousands ha)

Location	CLI Capability Classes for Agriculture														Organic soils	%	Water parks and urban areas	%	Total	%
	1	%	2	%	3	%	4	%	5	%	6	%	7	%						
Atlantic Provinces			611	2.5	2,561	10.4	2,544	10.4	2.352	9.6	2,903	11.9	9,350	38.2	3,695	15.1	442	1.8	24,458	100
Nfld.					5.5	.1	62	6	388	3.6	2,891	26.8	3,742	34.7	3,460	2.1	226	2.1	10,775	100
P.E.I.			261	45.9	157	27.6	23	4.0	98	17.3			28	4.8	28	9.5			568	100
N.S.			178	3.0	1,056	18.0	448	7.7	94	1.6	6.1	9.1	3,895	66.4	137	2.3	48	.8	5,862	100
N.B.			173	2.4	1,343	18.5	2,011	27.7	1,772	24.5	5.6	.1	1.686	23.2	96	1.3	163	2.3	7,261	100
Central Canada	2.263	3.7	3,336	5.3	4,660	7.3	5,732	9.1	3.546	5.6	1,201	1.9	34,887	55.3	3,422	5.4	4,057	6.4	63,104	100
Que.	14	.2	976	2.9	1,381	4.2	2,830	8.8	1,636	5.0	8.9	9.1	21,851	66.8	1,268	3.9	2,633	8.2	32,598	100
Ont.	2,249	7.4	2,360	7.7	3,279	10.8	2,902	9.5	1,910	6.3	1,192	3.9	13,036	42.5	2,154	7.7	1,423	4.7	30,504	100
Prairies	2,069	1.9	13,044	11.7	19,090	17.1	16,766	15.0	21,482	19.3	10,025	9.0	6,308	5.7	13,199	11.8	9,630	8.6	11,612	100
Man.	184	.8	2,556	10.7	2,561	10.7	2,573	10.8	2,250	9.4	2,162	9.1	1,254	5.3	5,113	21.4	5,192	21.8	23,844	100
Sask.	1,072	2.8	6,446	16.8	10,082	26.2	4,252	11.1	7,799	20.3	4,065	10.6	284	.7	2,914	7.6	1,581	4.1	38,494	100
Alta.[2]	813	1.7	4,041	8.2	6,447	13.1	9,940	20.2	11,433	23.2	3,794	7.7	4,770	9.7	5,173	10.5	2,858	5.8	49,274	100
Canada[3]	4,332	2.2	16,991	8.5	26,312	13.2	25,042	12.6	27,379	13.7	14,130	7.1	50,545	25.4	20,316	10.2	14,129	7.1	199,176	100

Areas measured on 1: 250,000 scale maps of Soil Capability for Agriculture, Canada Land Inventory.

[1]The percentages are based upon the area of each province or region covered by CLI. To convert the percentage data for Canada to values based upon the total land area, multiply the percentage values by 0.22.

[2]For Alberta Class 1 area includes 105,100 ha of Irrigated soils, Class 2 area 144,000 ha, and Class 3 area 158,500 ha.

[3]Canada total does not include British Columbia; estimates for B.C. are: 600,000 ha in Classes 1 and 2, 1,400,000 in Class 3 and 2,600,000 in Class 4.

TABLE 6

Distribution of Good Agricultural Land by Regions and by Provinces

	Percentage of Canadian Total	
	Classes 1 and 2	Class 3
Martime Provinces	2.8	9.2
Prince Edward Island	1.2	0.6
Nova Scotia	0.8	3.8
New Brunswick	0.8	4.8
Central Canada	25.5	16.8
Quebec	4.5	5.0
Ontario	21.0	11.8
Western Canada	71.7	74.0
Manitoba	12.5	9.2
Saskatchewan	34.3	36.4
Alberta	22.1	23.3
British Columbia	2.8	5.1
Total	100	100

NOTE:

Based on the data presented in Table 5.

Newfoundland has been excluded because of relatively insignificant areas of good agricultural land.

marshland area extends over some 17 million hectares. If one-half of this number were used for emergent biomass energy plantations, approximately 5 % of present total energy requirements in the U.S. might be met.

Land Resource Base for the Proposed Energy Crops

In Canada, despite the large number of local and regional studies the wetlands have never been studied in a systematic manner. The wetlands have been, over the decades of agricultural development, relegated to something of a nuisance in the farmland. For this reason, reliable estimates of wetland distribution in various parts of Canada are not available. However, recent efforts by the National Wetlands Working Group are beginning to provide a systematic assessment and classification of wetlands in Canada (Zoltai and Pollett, 1983). They estimate the total wetland area in Canada to be about 170 million hectares or approximately 18% of Canada's land surface. But the lack of an accepted definition of wetlands and the absence of reliable information about the distribution of agricultural and forest areas have made it impossible to arrive at clear estimates for the non-agricultural and non-forest areas in Canada. However, some estimates of the potential land base available in Canada for raising wetland energy crops have been computed using the data from Statistics Canada, Energy,Mines and Resources and the National Wetlands Working Group and are presented in Table 7.

The significant differences between the estimates are mainly due to the different interpretation of what a 'wetland' constitutes and the method used to arrive at the figures. These estimates should be used with the following definitions.

Estimate 1

'WETLAND' refers to the areas represented on the 1:250,000 maps of the National Topographic System, by the symbols for "inundated lands, seasonal", "marsh or swamp", "alkali flats", "string bogs", and "foreshore flats".

Estimate 2

'WETLAND' is defined as land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophylic vegetation, and various kinds of biological activity which are adapted to a wet environment.

'WETLAND', therefore, includes:

- Peatlands, characterized by more than 40 cm peat accumulation,
- Wet areas characterized by Gleysolic or peaty phases of Gleysolic soils,
- Shallow open water areas, generally less than 2 m deep,
- Areas modified by water control structures, and
- Areas which are tilled and planted but, if allowed to revert, again become saturated for long periods and associated with hydrophilic vegetation.

Estimate 3

'WETLAND' in this estimate includes all areas not presently used for agriculture, not being considered for future development for any agricultural activity, and those areas not occupied by forest or forest-oriented activities.

The estimates have been obtained as follows.

WETLAND AREA AVAILABLE = (Total Land Area) - (Total Agriculture)
- (Total Forest) - (Other Defined Areas)

TABLE 7

Potential Land Base Available for Wetland Energy Crops

(km^2)

Region	Estimate 1	Estimate 2	Estimate 3
1. Newfoundland	17,075	37,246 - 110,189	32,372
2. Prince Edward Island	50	0 - 462	577
3. Nova Scotia	825	1,571 - 8.965	10,162
4. New Brunswick	1,600	1,017 - 5,545	4,173
5. Quebec	53,200	85,952 - 263,841	718,511
6. Ontario	285,950	286,368 - 467,629	274,878
7. Manitoba	152,525	175,463 - 303,812	235,875
8. Saskatchewan	28,525	51,733 - 141,753	228,094
9. Alberta	117,125	116,196 - 243,699	175,460
10. British Columbia	34,700	43,900 - 118,623	401,358
11. Yukon & NWT	90,225	161,740 - 397,643	3,198,423
CANADA	781,800	961,186 - 2,062,131	5,279,507

Estimate 1: Obtained from grid measurements in AREA OF WETLANDS, produced by the Surveys and Mapping Branch, Department of Energy Mines, and Resources. Ottawa, Canada 1973.

Estimate 2: Obtained from WETLANDS OF CANADA prepared by the National Wetlands Working Group, Canada Committee on Ecological Land Classification, 1981.

Estimate 3: Obtained from 1980-1981 Canada Year Boom and Liquid Fuels from Renewable Resources: Feasibility Study. Prepared by InterGroup Consulting Economists Ltd. Winnipeg, Manitoba for Government of Canada, March, 1978.

The three estimates differ significantly in the total areas available in Canada as well as in their estimates of 'wetland' areas in each province. The total available area for the country ranges from 781,800 km^2 to about 5,279,507 km^2. The National Wetland Working Group suggests that the total area of wetlands in Canada is around 170 million hectares or 18% of Canada's land surface. On the other hand, studies conducted by the Department of the Environment which form the basis for the estimate 1 indicate that the wetlands occupy about 8.19% of the total area of Canada while the grasslands including the croplands occupy about 6.71%. The distribution and classification of wetlands given by the NWWG studies are given in Figures 2 and 3.

Growth Habitat of Aquatic Plants

Aquatic plants or wetland vegetation can be submersed, floating or emergent. The first two types require standing water throughout the

Fig.2. Wetland Regions of Canada.

A_H= High Arctic; A_M= Mid Arctic; A_L= Low Arctic; S_H= High Subarctic; S_L= Low Subarctic; S_A= Atlantic Subarctic; B_H= High Boreal; B_M= Mid-Boreal; B_L= Low Boreal; B_A= Atlantic Boreal; T_E= Eastern Temperate; T_P= Pacific Temperate; O_A= Atlantic Oceanic; O_P= Pacific Oceanic; P= Prairies; P_I= Intermountain Prairies; M_A= Mountain Complex;

(Figure taken from Zoltai and Pollett, 1983)

Fig.3. Distribution of Wetlands in Canada, expressed as % of total Land Surface.

(Figure taken from Zoltai and Pollett, 1983)

the season, require special harvesting procedures and necessitate constant supervision for achieving maximum densities. The emergent species offer the greatest promise in terms of growth conditions, maximum productivities achievable and ease of management. The wetlands or marshes contain a large variety of species with wide ranging growth rates, photosynthetic efficiency and annual yields. An exhaustive study of the emergent aquatic plants for biomass energy production was carried out by Solar Energy Research Institute (SERI) for the U.S. Department of Energy in 1982 (Kresovich et al, 1982). The main botanical characteristics of some common aquatic species are listed in Table 8. These have been culled from several major studies in the U.S., most of which are referenced in the SERI report. Numerous studies have been conducted on primary productivities, species diversities, and physiological processes in aquatic eco-systems. Most of the important work has been summarized in some recent reviews (Kresovich et al, 1982, Kresovich et at, 1981, Good et al, 1978). Emergent aquatic plants collectively represent a wide range of growth habits. Some are halophytic (able to grow in saline substrates), while some prefer freshwater, and others grow in fresh, brackish or salt marshes. Some species grow in specialized environments such as sphagnum bogs, calcareous regions and argillaceous substrates. However, it has been shown (Kresovich et al, 1981) that a plant's indigenous environment does not necessarily exclude it from a contrasting or modified managed habitat. Thus many of the aquatic species possess a great deal of latitude in their habitat potential which renders them suitable for managed cultivation.

Propagation and survival characteristics of these plants are also

TABLE 8

Botanical Characteristics of Emergent Aquatic Species

Species	Common Name	Characteristics, Habitat
Arundo donax	Giant reed	Perennial, creeping rhizomes 2 - 8 m tall; irrigation ditches, sand bars, marshes.
Butomus umbellatus L.	Flowering rush	Perennial, rhizomatous, 1.2 m tall, mud, shallow to deep water.
Carex rostrata stokes.	Beaked sedge	Perennial, rhizomatous, 1.2 m tall, shallow waters, swamps.
Cyperus esculantus L.	Yellow nutsedge	Perennial, creeping rhizomes, 15 - 65 cm long culms; shallow ponds, lakes streams.
Cyperus papyrus L.	Papyrus	Perennial, rhizomatous, 1.2 - 4.6 cm tall, banks and shores, flowing waters.
Eleocharis dulcis	Chinese water chestnut.	Perennial, rhizomatous, 0.3 - 1.5 m tall; bottom mud or sand, shallow water, freshwater and brackish.
Juncus effusus L.	Soft rush	Perennial, rhizomatous, 0.3 - 1.8 m tall; meadows and freshwater peaty swamps, bogs.
Juncus roemerianus S.	Rush	Perennial, rhizomatous, 0.5 - 1.5 m tall; brackish ditches, coastal marshes.
Justica americana (L) vahl	American water willow	Perennial, abundant, thick, superficial rhizomes, 0.3 - 1.5 m tall, streams, best in 15 - 45 cm of water.
Paspalum vaginatum S.	Salt water couch	Perennial, rhizomatous; 5 - 25 dm long; dry, sandy beach soils.

Table 8 (cont'd)

Species	Common Name	Characteristics, Habitat
Phalaris arundinacea L.	Reed canary grass	Perennial, rhizomatous, 0.6 - 2 m tall; marshes, wet meadows.
Phragmites communis Trin	Common reed	Perennial, rootstalk coarse, 1.5 - 6 m tall; fresh to alkaline marshes.
Saccharum spontaneum L.	Wild sugar cane	Perennial, rhizomatous, over 8 m tall, along river bends.
Scirpus acutus Muhl	Harstem bulrush	Perennial, rhizomatous; 0.5 - 3 m tall, shallow ponds, sloughs, calcareous regions.
Scirpus americanus Pers.	Three-square rush	Perennial, elongate rhizome; up to 1.5 m tall; shallow water, abundant in saline, brackish or alkaline waters.
Scirpus fluviatilis Torr.	River bulrush	Perennial, rhizomes elongate; 2 m tall, sloughs.
Scirpus robustus Pursh.	Stout bulrush	Perennial, rhizomatous; 0.7 - 1.5 m tall; brackish or saline ponds.
Scirpus validus Vahl.	Soft-stem bulrush	Perennial, scaly rhizome: up to 3 m tall, brackish or fresh shallow waters, marshes.
Spanrganeum erectum L.	Bur reed	Perennial, rhizomatous; 1.5 m tall; paludal.
Sparganeum eurycarpum Engelm	Bur reed	Perennial, rhizomatous: up to 1.5 m tall; paludal, sloughs, shallow waters.
Spartina alterniflora Loisel	Salt water cordgrass	Perennial, rhizomatous; up to 2.5 m tall; shallow water, salt marshes along sea coast.

Table 8 (cont'd)

Species	Common Name	Characteristics, Habitat
Spartina cynosuroides L.	Salt reed grass	Perennial, hard rhizomes, 1 - 3m tall, salt, brackish to fresh tidal marshes.
Spartina patens	Salt meadow grass	Perennial, slender rhizomes; 1.5 - 8 cm tall; saline marshes.
Typha angustifolia L.	Narrow-leaved cattail	Perennial, extensively rhizomatous, up to 1.8 m tall; Bay, marshes, marl lakes, fresh and brackish, basic or alkaline waters.
Typha latifolia L.	Common cattail	Perennial, thick rootstock, extensively rhizomatous, 1 - 3 m tall, shallow bays, sloughs, marshes, springs.
Zizania palustris L.	Annual wild rice	Annual, culms 1.5 m tall; water and mud of springs, marshes, lakes and ponds.

different. Some are annual, requiring planting each year and some are rhizomatous perennials which do not require to be planted every year as long as an adequate portion of the below-ground propagative material is left behind after harvest.

Rhizomatous plants have the advantage of augmenting the biomass harvested above-ground with the biomass available below ground, which can account for more than 50% of the total biomass yield in plants such as cattail. Species diversity in a wetland environment can be quite high, depending upon the nutrient status and water quality. Aquatic plants are more productive than terrestrial plants as, in general, they do not suffer from water deficit. The photosynthetic apparatus in aquatic plants has been examined by several investigators in great detail in recent years (McNaughton, S.J., 1970, 1967, Westlake, 1982, McNaughton et al., 1974). Although a number of plant species adapt the C_3 pathway for carbon utilization, there are several species which exhibit highly efficient C_3 pathway or the C_4 pathway which results in impressive biomass yields. Table 9 which includes data from several studies on the physiology of aquatic plants shows the range of CO_2 assimilation which, in turn, influences the annual biomass yields. Although cattail uses the C_3 pathway for carbon assimilation its efficiency of carbon utilization is quite high resulting in very high annual biomass yields. The measured productivities on an annual basis are given in Table 10 which span a wide range of values depending upon the substrate conditions and the species competition in the wetland environment. Aquatic plants, as discussed before, are not generally limited by water and they maximize the solar energy collection and conversion by means of vertical leaf arrangement and a very high

TABLE 9. PHYSIOLOGICAL CHARACTERISTICS OF EMERGENT AQUATIC SPECIES.

Species	Photosynthetic Pathway	Ranges of Rates of CO_2 Assimilation mg $dm^{-2} h^{-1}$	Ranges of Crop Growth Rates g $m^{-2} d^{-1}$	Rate of Net Production t Dry Matter $ha^{-1} yr^{-1}$	
				Above Ground	Below Ground
Arundo donax L.				12-38	
Butomus umbellatus L.				15-25	
Carex rostrata Stokes				5-10	2-4
Cyperus esculentus L.	C4			10-23	1-5
Cyperus papyrus L.	C4	26	50	30-50	
Distichlis spicata (L.) Greene	C4*		5-10	7-15	4-14
Eleocharis dulcis (Burmf .f.) Trin.					7-18
Juncus effusus L.	C3*				
Juncus roemerianus Scheele	C3	15-25		17-34	1-13
Justicia americana (L.) Vahl			25-48	10-25	
Paspalum vaginatum Swartz	C4			3-7	
Phalaris arundinacea L.	C3	15-30		8-20	
Phragmites communis Trin.	C3	15-30	25-48	15-35	1-14
Saccharum spontaneum L.	C4	50-60	18-37	15-40	
Scirpus acutus Muhl.	C3*			9	
Scirpus americanus Pers.	C3*			4-9	4-18
Scirpus fluviatilis (Torr.) Gray	C3*				
Scirpus validus Vahl	C3*			1-2	3-5
Scirpus robustus Pursh.	C3*			11	
Sparganium erectum L.			12-36	15-35	
Spartina alterniflora Loisel	C4		5-10	5-22	1-8
Spartina cynocuroides (L.) Roth	C4		5-10	4-22	1-13
Spartina patens (Ait) Muhl	C4		5-10	5-24	1-2
Typha augustifolia L.	C3		25-48	10-30	9-36
Typha latifolia L.	C3	22-34	25-48	11-33	14-26
Zizania palustris L.	C3*			2-4	>1

* Information not found on photosynthetic pathway; however, other species within the given genus exhibit the identified pathway.

TABLE 10

BIOMASS YIELDS OF SOME COMMON AQUATIC PLANTS
(gm^{-2} dry weight)

Species	Above Ground	Below Ground
Polygonum leersia	523 - 2,142	507
Nuphar advena	245 - 1,175	1,146 - 4,799
Pontederia peltandra	486 - 1,286	2,463
Acorus calasmus	605 - 1,174	-
Hibiscus palustris	1,354 - 1,714	-
Zizania aquatica	560 - 2,091	721
Spartina cynosuroids	560 - 3,543	-
Phragmites communis	497 - 3,999	7,180
Acnida cannabina	768 - 1,112	560
Bidens spp.	900 - 1,109	-
Phalaris arundinacea	566 - 1,370	-
Lythrum salicaria	1,313 - 2,104	-
Ambrosia trifida	1,160 - 1,227	-
Sagittaria latifolia	214 - 649	-
Spartina patens	445 - 1,525	-
Juncus roemerianus	1,082 - 1,602	-
Planicum virgatum	326 - 4,029	-
Scirpus spp.	150 - 6,400	-
Spartina alterniflora	445 - 3,300	6,353
Carex spp.	400 - 630	-
CATTAIL SPECIES:		
Typha latifolia	400 - 2,252	200 - 1,400
Typha X glauca	1,361 - 2,320	2,400 - 2,650
Typha elephantina	975 - 2,464	1,542 - 5,269
Typha angustifolia	564 - 1,647	306 - 2,861

leaf-area-index. It is not unusual to find leaf-area-index values between 10 and 15, which are quite high compared to the values for grain crops. The surplus of water in the wetland environment helps the aquatic plants to achieve high fluxes of CO_2 fixation.

To summarize:

. Valuable agricultural lands form only about 13% of the total land area, of which about 60% is suitable for field crops and about 40% is suitable for pasture.

. Diversification of valuable agricultural areas for energy crops would produce inevitable conflicts and confusion, and the economics of these new ventures would depend upon the relative world prices for oil and grains.

. There are enormous land areas as wetlands, peatlands and marginal lands available in Canada which have been neglected over the decades of agricultural development. A large percentage of these areas can be developed into energy farms.

. Development of energy farms in these areas can be planned without deleteriously affecting the wildlife, waterfowl, or the natural flora.

. The wetland utilization for raising energy crops will avoid the food-feed-energy conflicts which occur with the use of conventional grain crops or the large scale processing of agricultural residues for energy.

. Aquatic plants exhibit high to very high productivities, not matched by any of the conventional crops.

. Aquatic plants pose lower nutrient demands than the conventional crops and can obtain almost all of their needs from the soil. They have wide tolerance for salinity, water quality, water depth, and environmental

conditions.

. Rhizomatous plants produce larger biomass yields when completely harvested, and therefore, become efficient producers for a given land area.

. Pesticides and insecticides are not needed.

. There are economic benefits to be gained from the utilization of marginal lands, in terms of northern development and job creation.

CATTAIL AS A COMPETITIVE ENERGY CROP

It appears, from what has been discussed in the previous section, that a definite opportunity exists for utilizing the vast areas of marginal lands, peatlands and wetlands for raising energy crops. The most important aspect of this approach is that it relieves the pressure on the valuable agricultural lands while establishing an alternative land base for non-agricultural benefits. It is, therefore, necessary to identify the prime candidate from among the aquatic plant species in the wetland environment, which can be cultivated, managed and developed into a viable energy crop. The primary purpose of this report is to propose cattail as a competitive energy crop and examine its energy related characteristics compared to other conventional bioenergy sources.

It is imperative that a scientific evaluation of a potential energy crop should follow a rationale which purports to identify the strengths and weaknesses of the candidate crop and establish operational scenarios where the crop can seriously contend with the conventional crops. The following parameters are considered to be important in determining the economic and scientific merits of an energy crop:

- Biomass Availability
  - land base
  - productivity
  - photosynthetic apparatus
  - morphology; leaf-area-index
  - environmental tolerance
  - rhizome-to-leaf biomass ratios
  - nutrient requirements

- Biomass Preparation
  - harvesting
  - drying
  - densification
- Biomass Characteristics
  - carbohydrate fractions
  - pre-treatment requirements
  - hydrolysis
  - fermentation efficiency

The schematic shown in Figure 4 considers the most important components in the Energy-from-Biomass processes. These are discussed in the light of the available data from published works relevant to the North American context. It is the intent of this report to examine the potential of Cattail as a viable energy crop on the basis of this available information. An exhaustive literature search was conducted at the beginning of the study and a near-complete compilation of all published literature spanning a wide range of government and non-government documents was put together for this purpose. Major references used in the preparation of this report are given at the end.

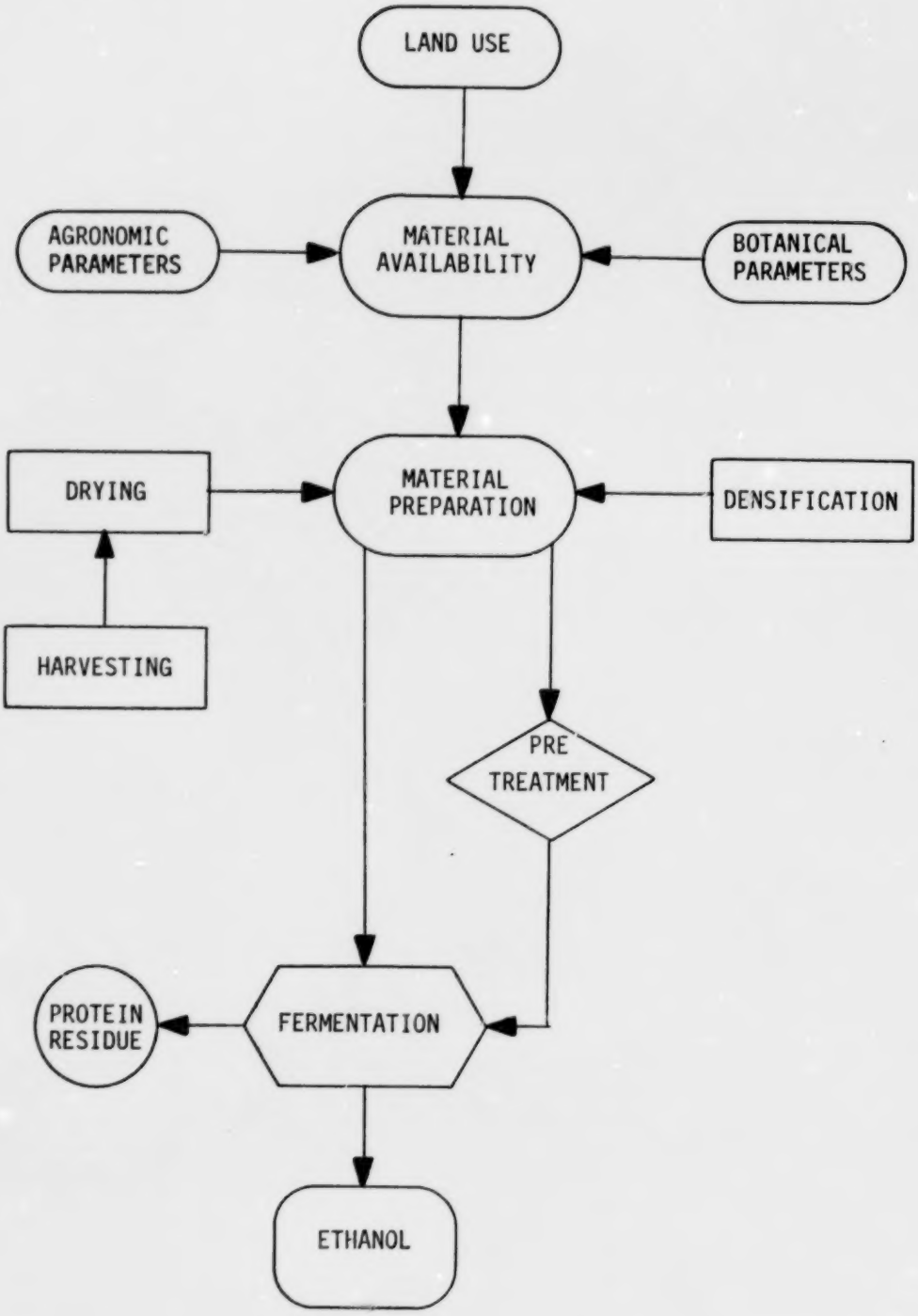
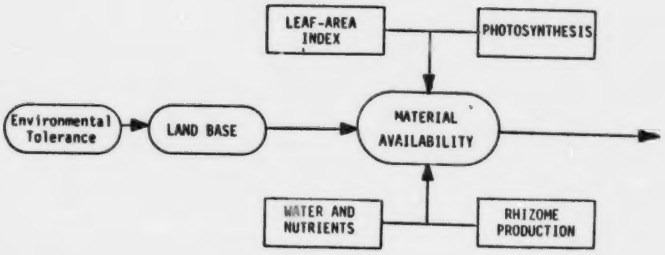


FIG. 4. A PROCESS SCHEME SHOWING THE SCIENTIFIC AND TECHNICAL COMPONENTS FOR DERIVING ENERGY FROM BIOMASS.



Environmental Tolerance and Land Base

Cattail, as an aquatic species, occurs in almost all places in the world, and is indigenous to North America. In Canada, it is abundantly common in wetlands, flooded lands, and peatlands from Newfoundland to Vancouver Island, and in the northern parts of Yukon and NW Territories. It occurs in moist places without any standing water as well as in habitats with permanent water more than a metre deep. This versatility of the plant naturally increases its potential for cultivation in a variety of agriculturally marginal lands. On the Prairies alone there are approximately between 300,000 and 700,000 km^2 of wetland area, and it is possible to utilize large patches of this land for cattail cultivation. The wetlands are invariably flatlands making them easily approachable by machinery. In the northern parts of Canada the wetland utilization for energy farms can be considered without adversely affecting the local wildlife or introducing massive changes in the ecological balance. The wetlands occur in wide ranging shapes and sizes, depths and vegetation and are classified into temporary, intermittent and permanent types depending upon their water holding capacity. The unique topographic characteristics of wetland areas make it possible to drain temporary wetlands, which hold water only during the short period after spring runoff, into

the more permanent types. This creates a large useable and controlled area for raising cattail and provides a more assured water supply in other wetlands for waterfowl and wildlife. The hydrological work done by the Saskatchewan Research Council on the water balance of wetlands has documented the relationship between the regional groundwater and the permanence of wetlands.

Recent studies conducted in the Northern Minnesota peatlands have shown that cattails can be grown successfully to yield high plant densities (plants per unit area) in lands from which peat has been fully harvested (Pratt, 1983). Cattail crops can be used to revegetate or rehabilitate peat harvested lands.

A preliminary assessment of prairie agriculture indicates that soil salinity is encroaching upon valuable agricultural lands rendering them less and less suitable for crop production. The possibility exists that cattails when cultivated in saline soils can serve to reduce salinity in soils.

In a laboratory study (Kaushik, 1963), the cattail seeds were found to germinate in salinity levels up to 150 me/L (of 2:1 ratio of NaCl and $CaCl_2$). Maximum seed germination was attained within 6 to 8 days under all treatment conditions of salinity from 0 to 120 me/L. Salinity influenced the absorption of water by seeds. The amount and the rate of water absorption decreased as the salt concentration of the media was increased. The temperature did not exert significant influence on the rate of germination in the temperature range between 23°C and 30°C, although the germination rate decreased somewhat when the temperature increased to 35°C. Dry storage prior to sowing was good for germination

of cattail seeds. The moisture content of the seeds decreased somewhat when the salinity levels were increased from 0 to 180 me/L. At the salinity level of 90 me/L, less than 5% and less than 3% of the leaves developed chlorosis and tip burn, respectively. At the level of 180 me/L, the percentages were less than 65% and less than 66%, respectively.

Significant accumulation of ions such as Na, K, Ca, and Mg were observed in the same study (Kaushik, 1963), when cattails were grown in saline conditions. The data from the field experiments showed that cattails contained as high as 198.6 and 280.7 me/100 g of sodium and calcium respectively, on a dry weight basis. Decrease in available water due to high osmotic pressure of the substrate was found to be correlated with the depression in plant growth in salinized media. The plants may be starved of the nutrients essential for their growth at high salinity levels.

Salt tolerance range needed to achieve 50% germination and survival of cattail is given below.

TABLE 11

Salt Tolerance Levels for Various Stages of Cattail Growth to Permit at least 50% Germination or Survival

Stage	Range of Salinity Levels (milli mho/cm @ 25°C)
Seeds	5 to 7
Young Plants	5 to 7
Mature Plants	8 to 10

In the same study marshes containing catails in the Utah Bird Refuge were monitored for salinity changes during the season. The measured average conductance varied from a low of 3.4 milli mho/cm in May to a high of 14.5 milli mho/cm in September. These levels of salinity correspond to moderate salinity to severe salinity ratings in Saskatchewan soils.

Tables 12 and 13 show the effects of salinity, pH and aeration on young and adult plants.

The ability of cattails to grow and survive in moderately saline waters offers an additional opportunity to utilize saline soils to raise cattail in Canada. This may, over the years, help to gradually desalinate mineralized areas. Because tender seedlings and young plants are less tolerant to salts than mature plants, the data will help to control the water quality to promote seedling survival by reducing the salinity levels during the initial growth period.

Leaf-area-index, Photosynthesis and Productivity

Cattail exhibits a highly efficient C_3 pathway, fixing carbon via the alternative Calvin cycle or the Phosphate-pentose (C-3) pathway, incorporating photorespiration and glycolic acid oxidase activity. The observed maximum rates of photosynthesis at about 39.1 mg CO_2 g^{-1}, are very high for C_3 plants. Cattails have a very high rate of solar energy conversion in the Photosynthetically Active Radiation (PhAR). Extensive studies done on the physiology of cattail at the University of Minnesota have reported values from 3.8 to 6.1% for the photosynthetic efficiency, while Dykyjova, following his Czechoslovakian studies, reports a maximum *in situ* rate of 13.6% and a range of 5.6 to 10.9% in hydroponic cultures. Such high values of photosynthetic efficiency are quite rare in most C-3

Table 12. Effect of salinity on vegetative growth of adult aquatic plants.

Treatment (m.e./l.)	Diameter (cm)	Total length (cm)	Weight of top Fresh (gm)	Weight of top Dry (gm)	Weight of root Fresh (gm)	Weight of root Dry (gm)
			Cattail			
0	16.9	139.7	78.1	6.9	16.2	1.4
90	15.6	133.9	72.8	7.3	13.9	1.3
120	14.7	103.7	55.3	5.6	11.9	1.2
150	13.6	84.8	45.7	4.7	9.5	1.1
180	11.7	62.1	40.4	4.3	8.6	1.0

Table 13. Effect of salinity, pH and aeration on growth of young aquatic plants.

Treatment (m.e./l.)	Condition	Total length (cm) Begin.	Total length (cm) End	Fresh weight (gm) Begin.	Fresh weight (gm) End	Number of leaves Begin.	Number of leaves End	Length of top (cm) End	Length of root (cm) End
				Cattail					
0	Aerated (pH 5.5-6.0)	11.5	43.9	10.6	27.9	3.9	4.8	16.9	26.9
	Not aerated (pH 5.5-6.0)	11.3	36.0	9.9	22.7	3.3	4.4	17.5	18.4
	Aerated (pH 7.5-8.0)	11.1	39.7	9.8	25.8	3.2	4.4	20.9	18.8
	Not aerated (pH 7.5-8.0)	11.1	32.3	10.1	19.1	3.3	4.1	18.5	13.8
60	Aerated (pH 5.5-6.0	11.2	26.9	10.1	14.6	3.3	3.9	15.1	11.9
	Not aerated (pH 5.5-6.0)	11.0	20.3	9.9	9.9	3.2	2.7	12.4	7.8
	Aerated (pH 7.5-8.0)	10.9	21.6	9.7	12.6	3.2	2.9	9.6	11.9
	Not aerated (pH 7.5-8.0)	10.9	17.3	10.1	9.1	3.2	1.9	11.2	6.1

plants, and, in fact, these values approach or surpass the values for many C_4 plants. In addition, the unique canopy configuration with unusually high leaf-area-index endows the cattail with an ability for high "energy-capture" throughout the growing season. The measurements made in Czechoslovakia by Dykyjova show that the LAI (Leaf-area-index) reached a maximum of 18.2 during August with mean values around 14.0. In the Minnesota experiments the LAI increased from 0.28 to 7.64 during the growing season until September and later declined to almost zero in October. There is also a positive dependence of LAI on the plant density. In natural stands this has been shown to be true for densities from 10 per m^2 to about 110 per m^2.

There are some unique morphological characteristics of cattail which contribute to a high photosynthetic efficiency and, therefore, high primary productivity. The lowest layer of the stand receives an appreciable amount of incident radiation during the later part of the growing season when the more mature leaves at highest levels begin to decay. Moreover, the vertical blade-like structure of the cattail leaves shimmers with the wind movement and produces intermittent radiation fluxes at the lower levels. This produces better photosynthetic efficiency at over-saturating radiation fluxes. It is not surprising, therefore, that maximum seasonal productivities in the order of 40 tonnes/ha, have been observed in cattail.

There are other features which effectively contribute to the high productivity in cattail. The high mineral nutrient levels in wetland areas, abundance of organic matter, and the resultant colloidal formation make the nutrient limitation less important than in other environments.

In addition, abundant moisture due to flooded water levels, high water holding capacities of organic soils, and the ability of cattails to withstand anaerobic conditions in the root zone have helped the cattail marshes to flourish. The tables 14 and 15 particularly show the cattail productivity in natural stands under varying climatic conditions in contrast with the average yields from the conventional crops considered for energy in Canada.

Cattail grows as a monoculture and is easily propagated. It has few insect pests and diseases. It requires minimum management and fertilization and is not sensitive to soil conditions. In the field studies conducted by the Minnesota group the above-ground yields ranged from 11.0 to 23.0 tonnes per hectare and the below-ground biomass ranged from 23.0 to 47.0 tonnes per hectare of dry matter. The ratio of the below-ground to above-ground biomass varied from 0.5 to 2.0 through the growing season.

Water and Nutrients

Cattails have been observed to grow in thick stands in natural marshes even when the soil is only 'soggy' without any standing water. They can tolerate rapid changes in water levels as has been shown by the SRC's demonstration project at Humboldt, where the treated sewage from the cattail marshes are regularly drained completely before starting a new treatment run. The maximum depths that the cattails are known to survive in vary from about 1.0 metre to about 1.5 metre. Because of the unique cellular and stomatal structure of the leaves the plants transpire heavily, contributing to a large evapotranspiration loss. The transpiration losses can vary depending upon the meteorological and site-specific

TABLE 14

ANNUAL BIOMASS YIELDS FROM SOME CONVENTIONAL AGRICULTURAL CROPS CONSIDERED FOR ENERGY PRODUCTION

(Canadian results)

CROP	ANNUAL YIELD	REMARKS
Alfalfa 10% moisture	1.5-3.0 t/A	Needs well managed soils perennial crop.
Barley	0.9-3.5 t/A	Includes grain and straw
Fababeans 14% moisture	1.0-1.3 t/A	Susceptible to diseases. Yields are highly variable.
Sugarbeets	12.0 t/A	Field weight.
tubers only	3.0 t/A dw	Labour intensive cultivation.
tops only	1.0-2.0 t/A dw	Hard on soils, recommended planting once in 3 years.
Jerusalem Artichoke		
tubers	4.0 t/A dw	Peak values.
tops	4.0 t/A dw	Peak values.
total	7.0 t/A dw	Peak values.
Wheat		
Glenlea variety	2.5-3.0 t/A	With significant fertilizer input. The values represent the total biomass including straw.
Pitic 62	1.8-2.5 t/A	

t/A = tons per acre, dw = dry weight basis

TABLE 15

DENSITY AND PRODUCTIVITY OF NATURAL CATTAIL STANDS

Location	Density (shoots m^{-2})	Standing Crop (gm^{-2})	Standing Crop (gm^{-2})	Total (gm^{-2})
New York	-	1731-1356	-	-
New Jersey	-	1227	1845	3072
Quebec	50	1504	-	-
Florida	25	920	-	-
Florida	38	1200	-	-
Oklahoma	-	730	804	1534
S. Carolina	-	530-1132	-	-
Texas	-	1336	2646	3982
Alabama	-	428-2252	-	-
Minnesota	18-67	534-2114	-	-
Nebraska	-	416	556	972
N. Dakota	-	404	912	1316
S. Dakota	-	378	892	1270
Wisconsin	-	1852	3200	5052
Wisconsin	-	1400	503	1903
Oregon	20	954	-	-
Czechoslovakia	-	3358	1779	5337
England	51	1118	-	-
England	-	1070	-	-
Poland	32	880	-	-
Poland	-	460-1620	-	-
USSR	14-67	564-1647	306-2861	4508
India	-	170-5272	155-4867	10139

AG = Above Ground: BG = Below Ground

1 tonne per hectare = 100 gm^{-2} of standing crop

conditions. A useful estimate is about 1.3×10^{-3} to 2.2×10^{-3} $m^3/d/m^2$, during the period from May to September.

The ability of cattail to survive in saline or mineralized water has already been discussed. The studies in the U.S. have shown that the plants survive in wide-ranging pH conditions from about 5.0 to 11.0, with understandable decline in productivity as the pH approaches the extreme values. The studies conducted by the University of Minnesota showed that the mean net productivity of cattail grown in pH of 4 and 8 declined to about 84% of the productivity at pH of 6.

Cattail stands can be established in freshwater as well as in highly enriched water such as raw or partly treated sewage. The Saskatchewan Research Council carried out extensive growth chamber and large scale field experiments from 1976 to 1983. The results clearly show that high density cattail stands can be produced when raw or partly treated sewage is used as the growing medium.

The major part responsible for the uptake of nutrients in cattail is the below-ground rhizome-root system. Therefore, the substrate nutrient status is more important than the nutrient content of the overlying water for supplying nutrients for the plant growth. The following sketch shows the factors contributing to nutrient absorption in aquatic macrophytes for submergent and emergent varieties. This reiterates that substrate provides most of the nutrients absorbed by emergent aquatic plants.

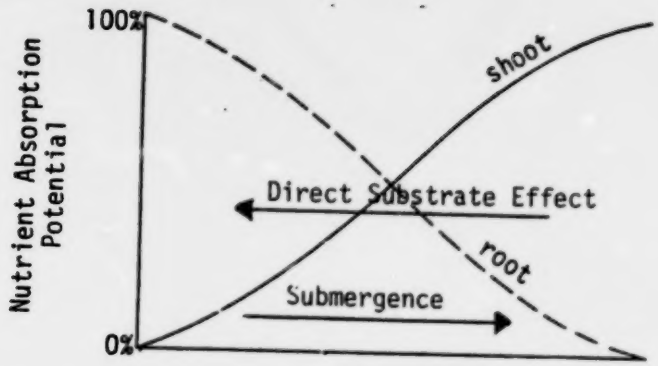


Figure 5. Tendency for root or shoot nutrient absorption by aquatic macrophytes.

Rhizome Production

Cattail, as described earlier, is a rhizomatous, perennial plant. Among the most aquatic plants cattail exhibits significant below-ground biomass growth and produces thick and starchy rhizomes. A single cattail plant can generate numerous plants within a growing season when optimum growing conditions are provided. Depending upon the nutrient status, species type and the hydrologic conditions the underground biomass can easily exceed the aerial biomass by a factor of two. Cattail rhizomes spread horizontally and are only about 0.3 m below the soil. Therefore, harvesting rhizomes by mechanical harvesters does not pose any problems. Table 16 gives the rhizome production relative to the aerial growth.

New rhizomes during the later part of June or July produce sprouts which begin to grow slowly during the first year of production. Growth continues until freeze-up when the growing sprout becomes dormant. They

can be as long as 0.35 m before going into dormancy. As soon as the air and water temperatures reach the optimum values for growth during the following spring, the sprouts become active again and grow to produce leaves. This growth can begin as early as April or May depending upon the temperature. On the other hand, adventitious buds which grow into the soil substrate develop to become new rhizomes.

Cattail plants are tied together by an underground network of stems or rhizomes growing parallel to the surface of the bottom. These stems interlace and interconnect, and parts of a single plant may spread over a considerable area and have many shoots. This produces a colony or clone which reproduces vegetatively and migrates outward to invade new areas. In fact, it is not unusual for a single clone to produce thousands of aerial shoots composed entirely of leaves and occasional fruiting stalks. The true stems are confined entirely to the underground portions or rhizomes.

The cattail rhizome has a number of important functions which are essential to the growth, survival and propagation of the cattail plant.

Carbohydrate Storage: The inner core of the rhizome is the principal area for the storage of reserve carbohydrates. Reserves are built up during the growing season and stored through the winter to provide food during the period when the new aerial shoot develops during the spring or early summer.

Plant Extension and Migration: During the growing season the plants are propagated by the rhizomes which produce new sprouts. This is an effective means of vegetative progagation which continually puts the plant in suitable new habitat and maintains it where it is already established.

Winter Survival: The rhizome is an organ well adapted to carrying the plant through the winter dormancy. In addition to its central food storage core, it has a spongy cortex which contains aerenchyma cells of the aerial shoot. In the winter, even though the aerial shoot is dead these aerenchyma 'tubes' are capable of conducting air to the rhizome to which it is attached. Although the rhizomes grow well under conditions of low oxygen and are capable of enduring anaerobic conditions for up to 13 days during dormancy they still need some oxygen to survive. Since most marshes become anaerobic for long periods during the winter months the cattail would die without this adaptation for securing oxygen from the surface.

A single rhizome can produce several active and latent buds during any season. The latent buds will start to grow whenever the growing rhizomes or the aerial shoots become injured or killed before they reach full development. Fully formed rhizomes range in length from a few centimeters to more than 0.6 m.

Old rhizomes, those produced during the previous growing seasons, are the principal storage organs for reserve carbohydrates. Cattail is essentially a starch accumulator, building up large quantitites of starch in the old rhizomes. In August, reserves begin to accumulate as sugars and and starch and very little is expended. These constitute the incoming materials as sugars which have not yet been converted into starch for final storage. The greatest concentration of total non-structural carbohydrates (TNC) occurs in the proximal portion of the old rhizome where it was stored mostly in the form of starch. The amount of TNC decreases somewhat in the more distal portions of the rhizome.

TABLE 16

RELATIVE PROPORTIONS OF DRY BIOMASS OF EMERGENT AQUATIC PLANTS

Species	Relative Proportions	
	Above Ground	Below Ground
Butomus umbellatus L.	>64	<36
Carex rostrata Stokes	50-77	23-50
Cyperus esculentus L.	69-80	20-31
Cyperus papyrus L.	78	22
Phragmites communis L.	>17	<83
Saccharum spontaneum Trin.	80-90	10-20
Scirpus fluviatilis (Torr.) Gray	25-66	34-75
Scirpus validus Vahl	40	60
Sparganium erectum L.	<70	>30
Typha augustifolia L.	30-50	50-70
Typha latifolia L.	30-50	50-70
Zizania palustris L.	63-81	18-37

After a period of growth both the old and new rizhomes contain almost the same amounts of TNC, but the type of carbohydrates involved varies considerably between them. In the new rhizomes, those produced during the current growing season, sugars become increasingly important progressing from the proximal portions to the more distal end or tip. Starches, which occur slightly in greater amounts than sugars in the proximal portion, decrease in the tip to less than half the amount of total sugars present. The new rhizomes contain the most amounts of reducing sugars. Wherever the growth is not taking place such as the regions closer to the aerial shoots, the carbohydrate storage begins to occur as starch.

Carbohydrates in Cattail Crop

A combination of a lack of research data and a traditional attitude towards aquatic biomass which considers them to be nothing more than a nuisance has discouraged the exploitation of cattail as an energy crop. The rhizomes of cattail account for the largest fraction of the total plant biomass and also function as the efficient and significant reserves of carbohydrates for wintering and for producing new shoots. Principally, they consist of starch and reducing sugars, and to a lesser degree, cellulose and hemicellulose. Most of the sugars produced in the leaves by photosynthesis are translocated to the rhizomes for starch systhesis. During the growing period some of the photosynthate is converted into structural carbohydrates in the leaves. As a result, the concentration of sugars or starch in the leaves is quite low. Typically, the leaves contain about 30 to 35% of cellulose, similar amounts of hemicellulose and about 15% of lignin, on a dry weight basis. Rhizomes contain mostly

starch and reducing sugars, with varying fractions of cellulose and hemicellulose depending upon the time of harvest. Table 17 gives the cellulose and hemicellulose values obtained from cattail samples from freshwater and nutrient rich media. A detailed analysis of reducing sugars, starch, pentosans, cellulose and fermentable material was worked out for cattail harvested from freshwater plants by Glass and Pratt at the University of Minnesota, during their thorough evaluation of cattail as an energy crop in North America. Table 18 shows the mean values of various carbohydrate fractions in the leaves, stalks and rhizomes during four harvest periods. The rhizomes contained up to 30% of starch and could produce up to 41% of fermentable material. Similar analysis of cattail samples obtained from Saskatchewan wetlands showed that rhizomes contained about 28% of starch and up to 25% of reducing sugars. These values are in sharp contrast with the values obtained from cattail grown in sewage. These are shown in tables 19 and 20.

As rhizomes play a significant role in the translocation, storage and utilization of carbohydrate reserves in cattail, it is clear that structural and non-structural carbohydrates undergo severe variations during the growth and wintering cycles of the plant. During the spring and early summer, the carbohydrate reserves in the rhizome begin to decrease from their post-winter values to support growth, respiration and plant propagation. As the photosynthate from the leaves increases during the summer, much of it in the form of glucose and sucrose is transported to the rhizomes for storage as starch. During the fall when the leaves become senescent, the reserves in the rhizomes reach a maximum. During the winter part of this is consumed for respiration. A detailed

TABLE 17

CELLULOSE AND HEMICELLULOSE CONTENT IN CATTAIL (% dry weight basis)

Sample	Cellulose		Hemicellulose	
	Freshwater	Nutrient rich	Freshwater	Nutrient rich
LEAVES				
SRC Growth Chamber.				
March 31.	-	20.83	-	-
June 23.	-	16.53	-	-
Sept 7	-	20.06	-	-
Dec 21	-	24.56	-	-
Humboldt				
Aug 10	-	28.72	-	-
Aug 10	-	20.83	-	28.85
June 16	-	24.27	-	-
June 16	-	26.65	-	-
July 20	-	23.56	-	31.56
Ditches	-	26.69	-	24.17
Ditches	-	25.02	-	36.74
Boyd (USA)	33.20	-	20.00	-
Minnesota	30.91	-	19.19	-
RHIZOMES				
SRC Humboldt Expt.	-	10.33-21.24	-	-
Minnesota	22.50-39.80	-	-	-
Dyck & Ladisch	34.00	-	25.00	-

TABLE 18

SUGARS AND STARCH CONTENT IN CATTAIL LEAVES, STALKS AND RHIZOMES (% dry weight)
(Pratt et al, 1981)

	July 18	August 23	Sept 23	Oct 25
Glucose + Fructose.				
Leaves.	5.3	7.0	-	-
Stalks.	8.6	8.9-12.3	5.8	7.1
Rhizomes.	10.9	9.9	4.6	4.0
Total Sugars.				
Leaves.	2.5	3.8	-	-
Stalks.	10.1-11.1	12.2-15.4	8.0	13.2
Rhizomes.	8.6	9.5	5.8	5.8
Starch.				
Leaves.	-	0.1	0.2	-
Stalks.	1.0	1.5-13.7	0.8-29.0	0.2-19.6
Rhizomes.	1.3	4.6	30.1	25.2
Fermentable Material.				
Leaves.	-	10.9	-	-
Stalks.	12.1	13.7-29.1	37.0	32.8
Rhizomes.	20.8	25.3	40.6	35.0

TABLE 19

STARCH AND REDUCING SUGARS IN FRESHWATER CATTAIL SAMPLES

RHIZOMES:	Starch (% dm)	Reducing Sugars (% glucose dm)
1972		
Blucher	12.1	10.44
1979		
St. Denis	14.6	9.74
Floral	17.4	12.44
Saskatoon	17.2	11.16
Aberdeen	15.3	17.86
1982		
Aberdeen (Mckay)	6.3	14.92
1983		
Floral, May 26, Site A	14.3	19.38
Floral, May 26, Site B	14.5	16.24
Floral, May 25, Site D	20.8	12.38
Floral, May 25, Site A'	18.5	15.18
Hague, May 31, Wagner S	8.9	18.48
Hague, May 31, Wagner NE	14.7	13.38
Aberdeen,May 26, Site C	27.6	17.04
Floral, July 26,Site B	7.1	23.74
Floral, July 25,Site C	-	19.80
Floral, July 25,Site D	-	24.78
Floral, July 26,Site A'	9.4	24.92
Aberdeen, Oct 25, Site C	15.3	9.78
Peterson, Oct 25,	19.3	6.98

TABLE 20

STARCH AND REDUCING SUGARS IN NUTRIENT RICH CATTAIL SAMPLES

RHIZOMES:	Starch (% dm)	Reducing Sugars (% glucose dm)
June 16, 1983		
Humboldt D_1	5.0	15.32
Humboldt D_2,D_3	6.1	13.88
Humboldt UL	7.9	19.80
July 20, 1983		
Humboldt, Ditches	-	10.08
Humboldt, UL	-	15.04
August 10, 1983		
Humboldt, L & UL	5.7	10.40
October 25, 1983		
Humboldt D_1	13.6	10.74
Humboldt UL	13.8	6.44

analysis of this variation over a two-year period was done by the Minnesota workers and the summarized data are presented in Table 21.

From what has been shown, it appears that the optimum time for harvesting the plants to maximize carbohydrate harvest for ethanol production is around September. During this period the leaves contain the maximum cellulose and hemicellulose. In most cases probably late August and September would provide the optimum time for harvesting the crop.

Dyck and Ladisch at Purdue University conducted laboratory trials for hydrolysis and fermentation of cattail rhizomes. Their studies indicate that,

1. Hot water wash extracted about 17% of the original dry weight of the rhizomes as sugars and other materials. These were identified as starch, uronic acids, sucrose, glucose and fructose.
2. After wash, the substrate contained 25% of hemicellulose, 34% of cellulose and 15% of lignin.
3. The hemicellulose could be completely hydrolysed to yield mostly glucose, xylose, arabinose, and lactic (uronic) acids. The conversion was essentially quantitative.
4. The final processing involving the treatment of the residue with a solvent followed by hydrolysis showed that 40% of the weight was converted to glucose, yielding a 3% sugar solution.
5. One kg of cattail rhizome can yield approximately 0.6 to 0.8 kg of fermentable sugars. Assuming that all of this can be fermented, one kg of cattail rhizome can yield in the order of 0.24 to 0.4 kg of ethanol.
6. Longer pretreatment can yield higher conversion of celluose.

TABLE 21. CARBOHYDRATE DISTRIBUTION IN CATTAIL RHIZOMES

Date	No. Samples[2]	Glucose plus Fructose %	Sucrose %	Total Sugars %	Starch %	% Starch + total sugars	Cellulose %	Pentosans %
6-14	30 (9)	7.7 ±0.8	7.1 ±0.7	14.8 ±1.2	7.6 ±1.1	22.4	29.7 ±2.8	12.2
7-9	33 (7)	11.1 ±0.6	7.3 ±1.8	18.4 ±2.3	0.5 ±0.1	18.9	27.8 ±1.9	14.6
7-18	21 (6)	10.9 ±0.5	8.6 ±0.7	19.5 ±1.9	1.3	10.8	26.1	—
7-30	76 (15)	10.3 ±1.2	5.5 ±2.5	15.6 ±3.1	4.6 ±1.5	20.2	25.8 ±3.9	13.7
8-23	43 (17)	9.9 ±2.7	9.5 ±2.1	20.7 ±4.4	15.2 ±3.8	35.9	29.9 ±0.9	10.9
9-25	16 (15)	4.6 ±0.8	5.8 ±1.1	10.5 ±1.5	30.1 ±2.4	40.6	22.5 ±1.9	7.5
10-25	24 (22)	4.0 ±1.1	5.8 ±1.0	9.8 ±1.2	25.2 ±1.1	35.0	26.6 ±0.7	8.7
		Winter						
5-3	27 (23)	4.1 ±1.8	6.1 ±2.0	10.2 ±3.2	22.2 ±0.9	32.4	29.4 ±0.7	7.2
5-14	33 (19)	3.2 ±0.6	4.5 ±1.4	7.7 ±1.7	28.5 ±2.9	36.2	31.8 ±0.7	8.1
5-21	23 (17)	3.1 ±0.6	4.6 ±1.5	7.7 ±1.7	22.8 ±2.3	30.5	29.3 ±1.5	6.9
5-29	24 (10)	3.5 ±0.7	4.7 ±0.4	8.3 ±0.6	24.8 ±4.1	33.1	34.1 ±1.1	9.8
6-14	11 (3)	14.3 ±0.7	9.1 ±3.0	23.4 ±2.1	4.6 ±1.9	28.0	27.0 ±0.6	12.8
7-9	11 (2)	18.4 ±1.3	3.2 ±0.8	21.6 ±2.1	0.4 ±0.1	22.0	30.5 ±0.8	17.2
7-18	66 (31)	16.2 ±3.0	5.9 ±1.9	22.1 ±3.0	1.3 ±0.1	23.4	28.6 ±3.1	12.1
7-30	5 (1)	18.3	5.1	23.6	0.4	24.0	27.6	15.0
8-23	15 (10)	9.1 ±4.1	6.6 ±1.5	15.7 ±3.8	25.5 ±6.5	41.2	29.6 ±0.2	11.0
9-25	8 (8)	5.8 ±2.1	6.6 ±1.7	12.4 ±4.1	21.7 ±2.5	34.1	26.3 ±1.8	9.0
10-25	5 (2)	10.4 ±3.7	9.5 ±2.2	19.9 ±4.5	20.8	40.7	25.4	11.1
		Winter						
5-3	6 (4)	8.3 ±4.7	7.8 ±1.8	16.1 ±6.2	23.7	39.8	39.8	29.4
5-14	14 (8)	7.1 ±2.7	7.2 ±3.1	14.3 ±4.6	10.4 ±4.6	24.7	32.5± 1.4	12.7
5-21	3 (2)	5.8 ±0.4	6.5 ±0.2	12.3 ±0.5	19.4 ±3.2	31.7	32.2 ±0.8	10.2
5-29	9 (2)	6.8 ±0.1	8.4 ±2.0	15.2 ±2.0	22.2 ±0.3	37.4	33.0 ±0.9	10.0

[1]Values are means plus or minus standard error of mean unless only 1 value given.

[2]Total number rhizomes. In ( ) no. of pools resulting.

Minnesota studies have also shown that cattail rhizomes yield approximately 40% fermentable material without special solvent-processing or pretreatment processes. In a different study, over 50% of the solids was converted into ethanol and CO_2.

The Minnesota studies further showed that,

1. Glucose, sucrose and fructose were the only sugars present in all portions of the plant.
2. The starch consisted of about 7% amylose and 93% amylopectin. Acid hydrolysis of this produced only glucose.
3. The lower portions of cattail, stalks and rhizomes, were quite comparable in sugar and starch, and hence the total fermentable material.
4. The total fermentable material reached a peak in September and and amounted to 37% of the dry matter in the lower portion of the stalk and 41% in the rhizome.
5. The pentosans which constituted some of the hemicelluloses were variable from 7% to 17%.
6. The starch and sugars in the rhizomes by the end of September exceeded the cellulose content by a factor of 1.5.

Seasonal variation in the growth and the carbohydrate distribution in cattail are shown in figures 6 and 7.

Harvesting

A key concern that has been raised frequently whenever the potential of aquatic plants as energy crops is discussed is the apparent impossibility of harvesting the plants. Granted that in Canada we are not accustomed to seeing harvesters carrying away loads of aquatic plants for

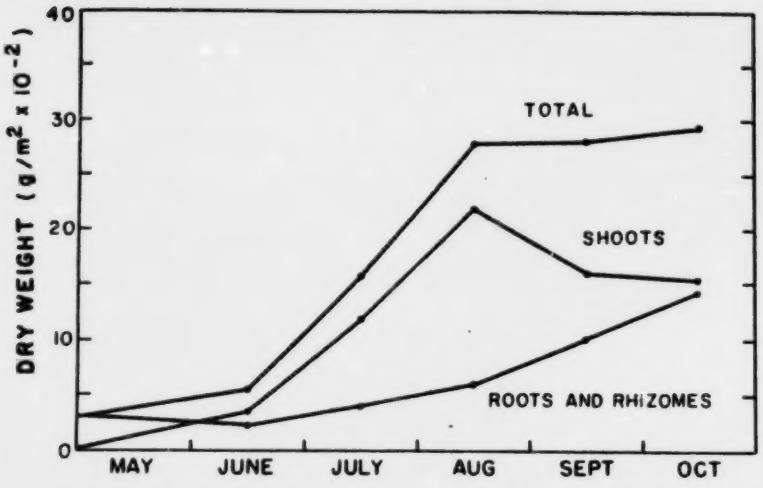


Figure 6. Seasonal development of roots and rhizomes, shoots and total biomass as mean monthly dry weight.

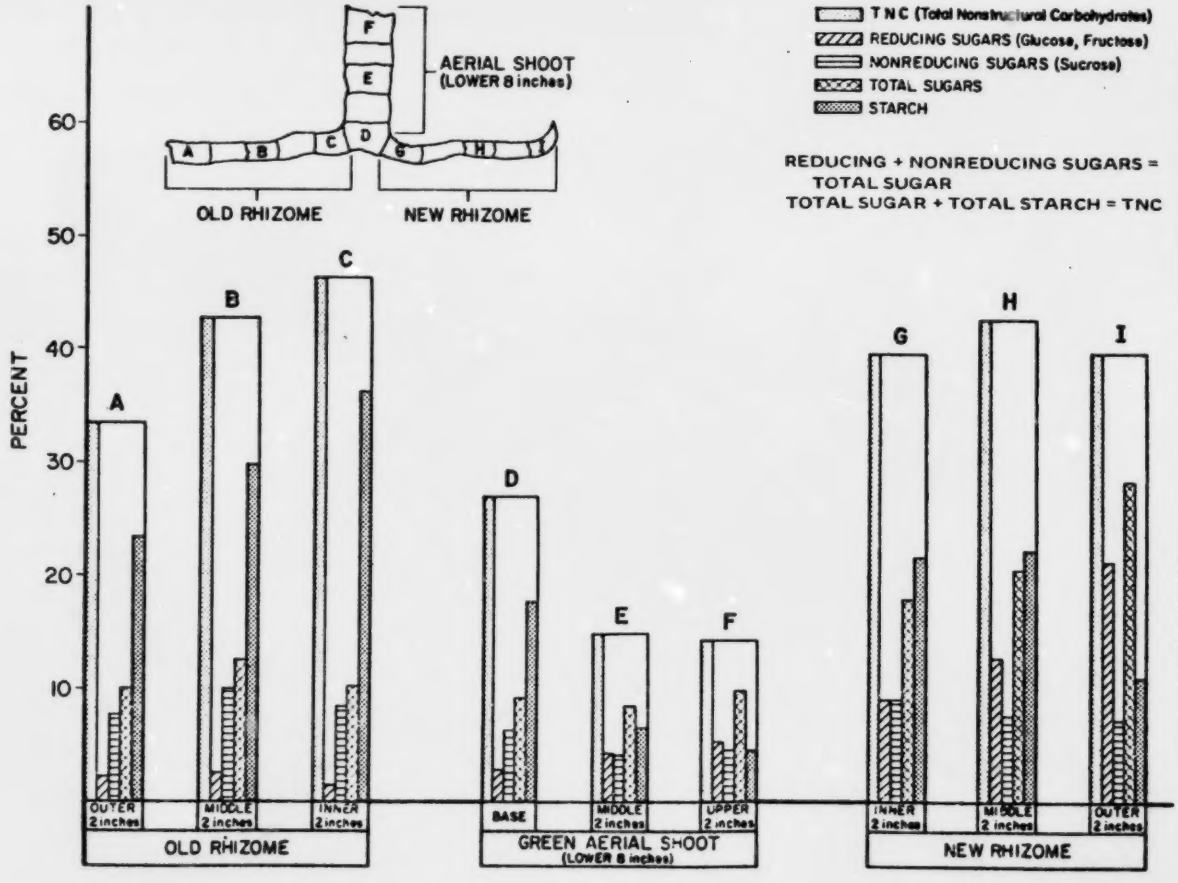


Figure 7. Carbohydrate distribution in cattail.

processing, the idea is not exactly outlandish nor is it out of the ordinary. In Europe and the Southeast Asia the aquatic biomass has been exploited to produce economically viable industries. In Romania 125,000 tons of dry common reeds (Phragmites communis) are mechanically harvested annually to produce about $10 million worth of paper pulp. This only accounts for 12,500 hectares of about 190,000 hectares of reedlands available for tapping. In Sweden, aquatic plants have been harvested quite successfully from marshes and wetlands by using amphibious machines since 1950's. Modern amphibious harvesters have been used regularly for winter cutting of large areas in northern Jutland (Denmark), at the Neusiedler Lake in Austria and Hungary, in the Danube Delta (Romania), the Euphrates-Tigris reed marshes in Iraq, and elsewhere. In Sweden alone, the reed covered areas - potential sources of aquatic biomass - are about 100,000 hectares, mostly in the form of small stands. Various adaptations of harvesters have been used to suit the terrain characteristics.

Some reed harvesters cut a maximum of 50 tons of reeds per day, approximately from 5 hectares. The reeds are bundled automatically and dropped to the ground. The bundles are then loaded manually on self-propelled or hitched trailer wagons and transported to a centrally located stacking area. Air boats with cutters have also been used to harvest and carry the reeds.

In the North American context, various harvesters with suitable modifications have been used in Mississippi, Florida, Minnesota and Ontario. In a trial conducted in southern United States, it was shown that one man can harvest about 1,500 of kg of fresh weight of plants per day from moderately dense stands of most species of aquatic vegetation.

In Ontario, the Ministry of Environment used Aquamarine Aquatic Weed Harvester (Model H650) and a self-transport experimental harvest to harvest emergent and submergent plants from Chemug Lake. Harvesting rates averaged about 0.15 hectares per hour and about 2,130 tonnes of vegetation were removed from about 263 hectares at an average cost of $325 per hectare.

A recent survey of 10 harvesting operations in Ontario, Canada and several locations in the U.S., puts the average cost at $240. per hectare, which includes harvesting and disposal of aquatic macrophytes. In some places the costs were as low as $150 per hectare.

Seiga Harvest Co. of Denmark manufactures amphibious harvesters which can harvest aquatic plants from about any kind of wetland. These models, in fact, float in water and exert very little ground pressure even under a load of 3 tonnes. About 4 hectares of area can be harvested in a day with the harvested material transported to a central location. A maximum rate of cut of about 30 bundles per minute is possible. This is about 5 tons/hr. or about 5,000 bundles of reed per day. The transporter when attached to the harvester can carry about 30 m^3 of harvested plants. The machine is able to traverse a terrain of widely differing surfaces and cross deep open water and ice. It can climb steep gradients of 30° to 40° and can climb out of water on to ice. It has a ground pressure of 40 g/cm^2 when empty and 100 g/cm^2 when carrying a load of 3 tons. Its speed over land ranges from 2.6 km/hr. to 11.8 km/hr. and from 3 km/hr. to 5 km/hr. on water. It has a turning circle of 12 m and has a fuel consumption of about 8 litres per hour.

The planting and harvesting trials conducted by Dr. Pratt and his associates in northern Minnesota used a version of this Seiga Harvester and a modified potato picker successfully in the cattail stands.

Figures 8 to 14 show the machines described above.

There is, however, a definite need to develop suitable harvesting and collection equipment which can be used on the uniquely different terrain conditions that the cattails would be grown in. Dewatering and drying of the harvested biomass would be critical if the production costs are to be kept down. It should also be recognised that the special cellular and stomatal structure of cattail leaves provides for rapid and massive transpiration of water, and when harvested the leaves retain almost 60 and 80% of moisture by weight. However, the same leaf structure allows for rapid loss of moisture from leaf tissues after harvest. In fact, the dry weight of the leaves is quite comparable to the dry weight in terrestrial plants short time after the harvest, at about 40 to 50%. If the plants are harvested after senescence of the leaves, in October and November, the aerial portions are sufficiently dry and would not need further dewatering or drying. Dewatering the leaves harvested during the growing season can be accomplished by using parallel rubber rollers or screw-type presses such as the Allis-Chalmers Screw Press in the field. Almost 60% of the moisture content can be removed and the pressed material weighs only about 40% of the initial weight.

Figure 8. Seiga harvesting equipment, 1983 model.

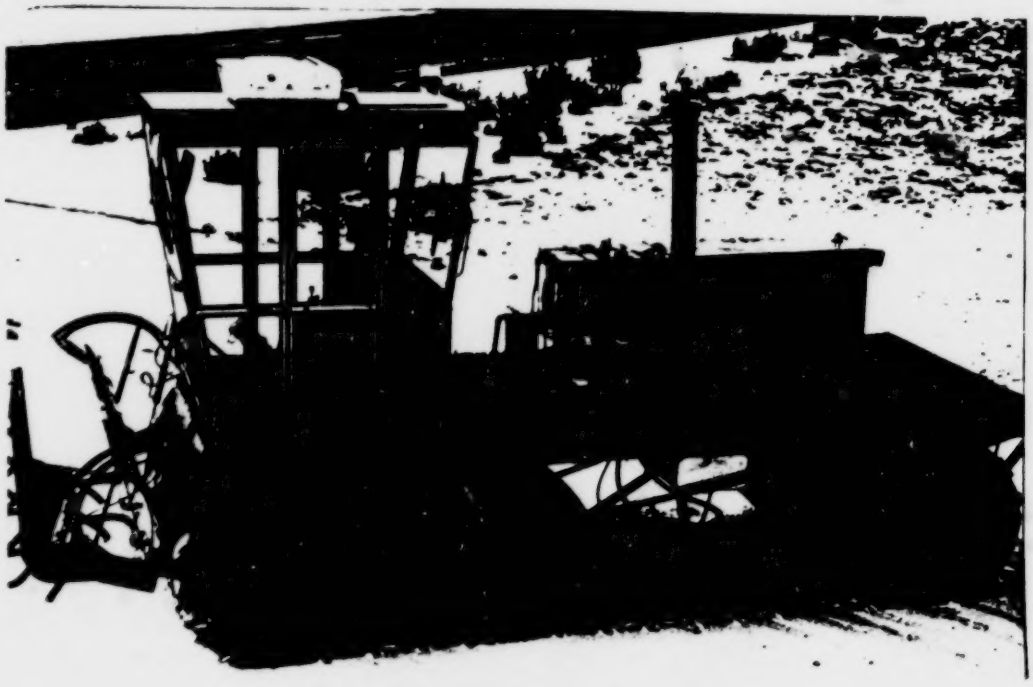


Figure 9. Seiga Rototiller, 1983 model.

Fig.10

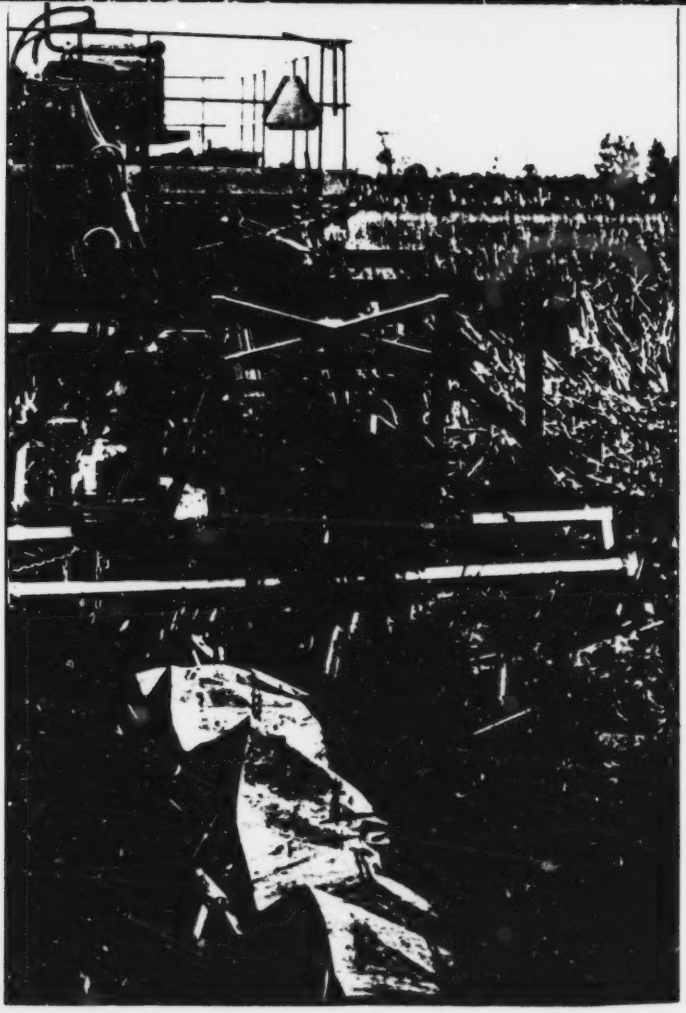


Fig.11

Harvesting cattail rhizomes using a modified potato picker, 1983.

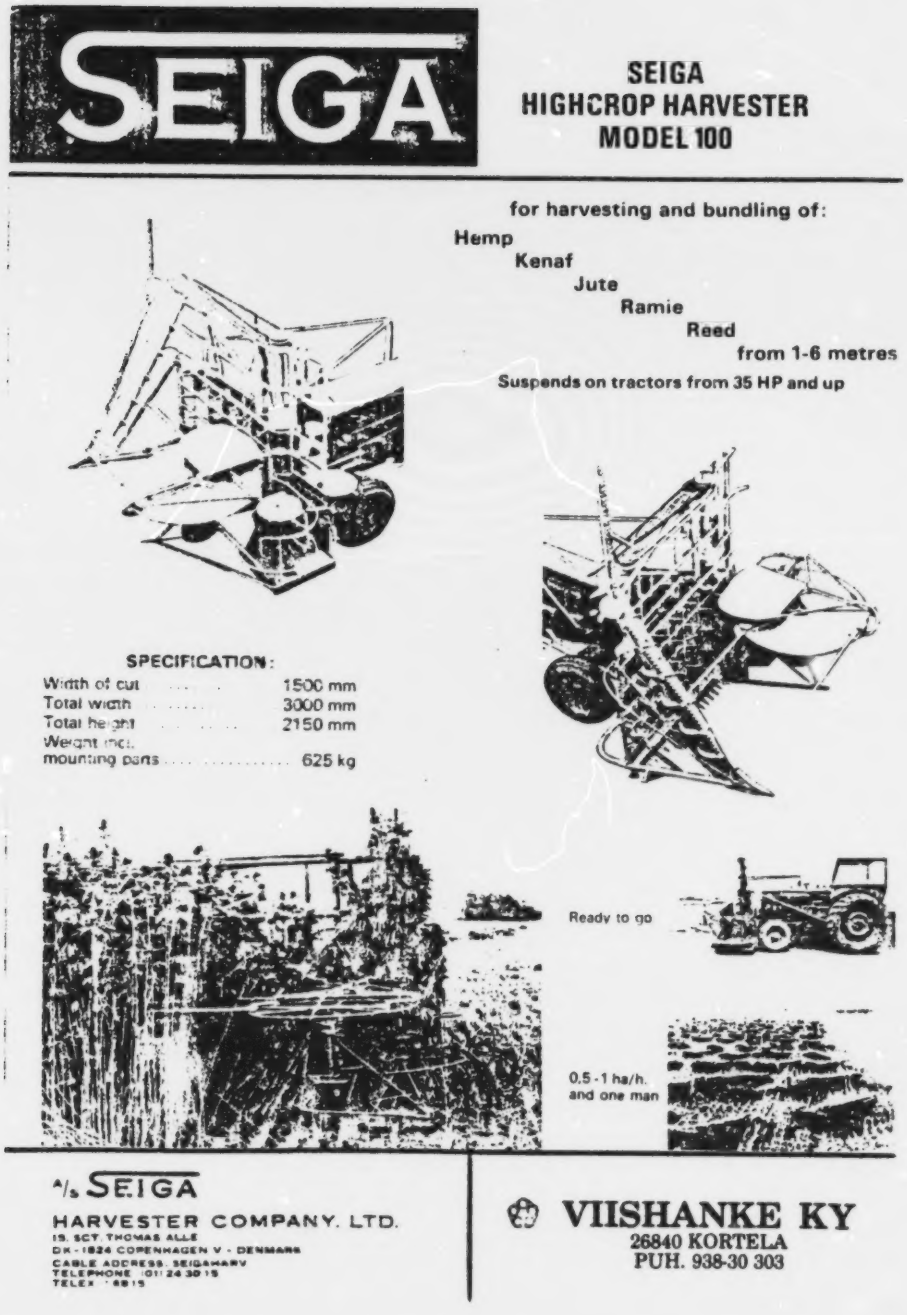
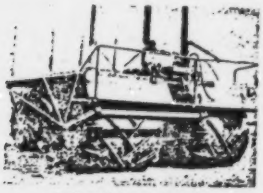


Figure 12. Reed harvesters for harvesting above ground biomass.

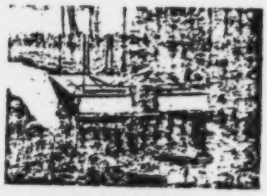
SEIGA AMPHIBIOUS TRANSPORTER

THE TORTOISE

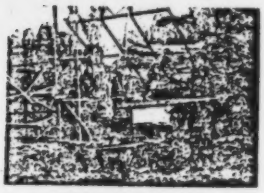
GROUND PRESSURE 40 GM/CM² (0.6 LB/IN²) UNLOADED



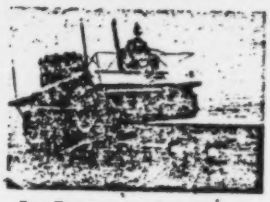
ON SHINGLE BEACH



IN LIQUID MUD



REED HARVESTING



Easy Transport over Long Distances

SPECIFICATION

Dimensions :

Length overall	4,62m (15 ft 1.80 in)
Width overall	3,10m (10 ft 2.04 in)
Height overall	2,08m (6 ft 9.84 in)
Deck height	1,40m (4 ft 7.08 in)
Deck length	4,00m (13 ft 1.44 in)
Deck width	3,10m (10 ft 2.04 in)
Deck area (including seat area)	12,40m² (133.0 ft²)
Deck area (clear rectangle)	11,63m² (125.0 ft²)
Ground clearance	0,60m (2 ft 0 in)
Wheel diameter (including tread)	1,30m (4 ft 3.12 in)
Wheel width	1,20m (3 ft 11.28 in)
Wheel base	2,85m (9 ft 4.2 in)

Weights :

Empty with Volkswagen Type 127 engine	1500 kg (3300 lb)
Empty with Lombardini Type LDA 673 engine	1650 kg (3630 lb)

Draught :

Flotation level in water, empty	approx. 18 cm (7 in) below axles
Flotation level in water, 1 ton load	approx 4 cm (1.8 in) above axles
Flotation level in water, 2 ton load	approx. 28 cm (10 in) above axles

A/S SEIGA HARVESTER COMPANY, LTD.

SCT. THOMAS ALLÉ 15, 1824 COPENHAGEN V, DENMARK

TELEPHONE 240915 TELEX 4815 CABLE: SEIGAHARV

Figure 13. Amphibious transporters for reed harvesters.

Giant Tortoise

Principal particulars

Dimensions:

Length, overall (with trailer hook)	6.40 m (21 ft 0 in)
Width, overall (with chain box 3.01)	3.15 m (10 ft 4 in)
Height, overall	2.08 m (6 ft 10 in)
Deck height	1.40 m (4 ft 7 in)
Deck length	6.00 m (19 ft 8 in)
Deck width	3.01 m (9 ft 10½ in)
Deck area	18.60 m² (200 ft²)
Ground Clearance	0.60 m (2 ft 0 in)
Wheel diameter (including tread)	1.30 (4 ft 3 in)
Wheel width	1.20 m (3 ft 11 in)

Weights:

Empty weight (no fuel or hydraulic fluid)	2900 kg (6403 lb)
Maximum weight with evenly distributed load	6000 kg (13248 lb)

Performance:

Load	2.5 to 3.0 tons, depending upon operating conditions
Speed, over land:	
1st gear	2.6 km/hr (1.6 mph)
2nd gear	4.7 km/hr (2.9 mph)
3rd gear	7.7 km/hr (4.8 mph)
4th gear	11.8 km/hr (7.3 mph)
Reverse gear	3.0 km/hr (1.9 mph)
Speed, in water	3 to 5 km/hr (1.9 to 3.1 mph)
Gradient climbing	30° to 40°
Turning circle	12.00 m (39 ft 4 in)
Fuel consumption	Approx 8 litres/hr (1.76 Imp gal/hr 2.1 US gal/hr)
Ground pressure:	
Empty	40 g/cm² (0.6 lb/in²)
With 3-ton load	less than 100 g/cm² (1.4 lb/in²)

Controls:

Throttle: Hand set, constant-speed governed.
Clutch: VW single-plate dry, 225 mm (8.86 in) dia., foot pedal operation.
Gearbox: Gear lever on extension from gear box.
Steering: Hand lever operated hydraulic system, rear wheels mounted on turnable, actuated by two hydraulic rams.
Brakes: Two foot pedals independently operating band brakes applied to drums on each output shaft of engine gearbox.

Electrical system:

12 V, 90 Ah battery. Two headlights, 130 mm (5.1 in) dia. Oil pressure indicator (pilot lamp). Battery charging indicator. Light switch. Ignition switch. Push-button starter. Engine running hour meter.

Tank capacities:

Diesel fuel, 52 litres (13.7 U.S. gal., 11.44 Imp gal). Hydraulic fluid, 50 litres (13.35 U.S. gal., 11.1 Imp. gal.). Esso Nuto H 44 or equivalent.

Hydraulic pumps for services:

Tandem hydraulic pumps, 170 bar (2498 lb/in²). Iotti Strozzi, two I.S.P. 7 (includes steering) 4 cm³/rotation. Iotti Strozzi, two I.S.P. 15. 15 cm³/rotation. Pressure relief valves: all 170 bar (2498 lb/in²).

Structure:

Welded steel, L-section, square section and channel section. Platform surface: non-skid aluminium alloy.

Components

Engine:

Lombardini air-cooled diesel, type LDA 833, 2472 c.c., 3 cylinder, 4-stroke, 41 h.p., 30.1 kW, governed to run at 2600 r.p.m. (continuous rating overload capacity) Dry weight: 235 kg (519 lb).

Gearbox:

VW rear axle assembly type 091 300 043 A (CU 091), differential 7:38

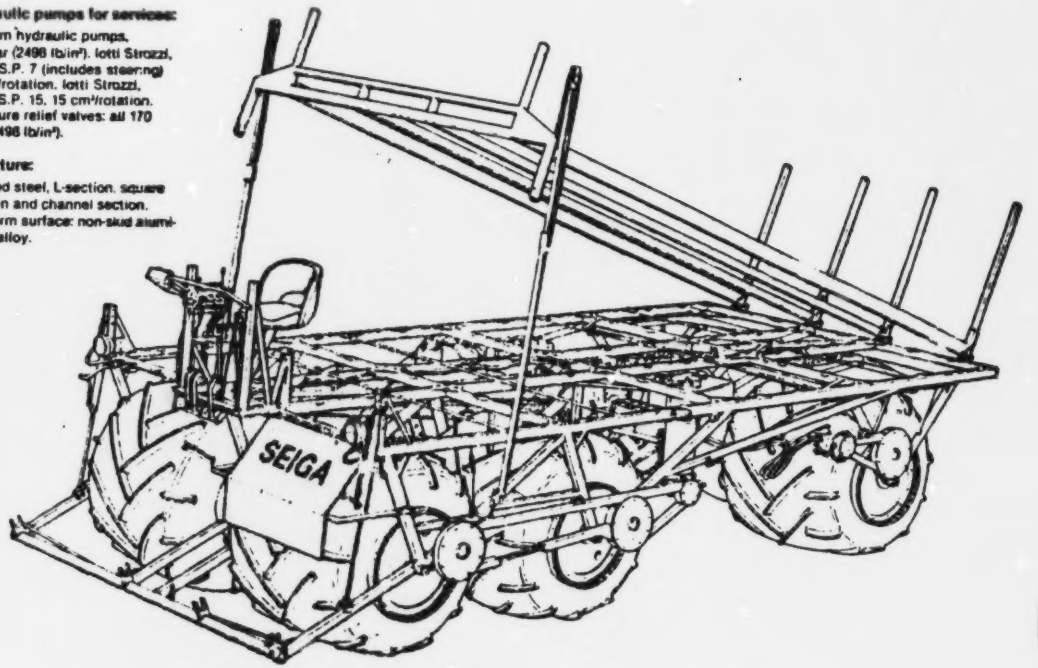


Figure 14. Mechanical details for an amphibious transporter, Seiga harvester.

Ethanol from Cattail

There are three basic and important advantages for cattail as an energy crop which will significantly enhance the economics of producing ethanol from it. These are:

1. Material Availability

Vast sources of land are available across Canada which are not at present being used for producing grains or forages. Cattail, as a feedstock, is obtainable from such 'wastelands' with minimum costs for maintaining proper hydrologic conditions. The land costs for grain crops and other food crops are quite high and are tagged to the economic forces affecting the agriculture. In addition, the opportunity costs of these grain substrates in terms of their conventional market will undoubtedly create conflicts and uncertainties.

Virtual absence of pests and diseases will eliminate the use of pesticides and herbicides and the corresponding capital investment. There is only a marginal requirement for fertilizer application for long term commitment of land for cattail production.

Capital investment, in terms of combines, swathers, cultivators and other agricultural equipment will be replaced by smaller capital outlay for planters and harvesters.

Multiple harvesting of leaves during the growing season, followed by rhizome harvesting during the fall will assure a continuous high yields of biomass during the year.

2. Carbohydrate Composition

The leaves contain a large percentage of cellulose and hemicellulose which yield hexoses and pentoses for fermentation upon acid or enzyme

hydrolysis. The rhizomes, on the other hand, contain largely starch and sugars which can be readily fermented to ethanol.

Total non-structural carbohydrates account for more than 50% of the rhizome weight on a dry weight basis. With simple pre-treatment and hydrolysis more than 60% of the total biomass can be converted to fermentable sugars.

3. Economic Impact of Cattail Utilization for Energy

Managed cultivation of cattail in the northern areas of Canada and in the marginal lands will create significant job opportunities in the northern as well as the populated areas of Canada. The spin-off from such ventures will also generate secondary industries to benefit the local communities.

Cattail leaves can be used to produce pelletized fuel for combustion in wood burning stoves and straw burners to heat homes and industries. Cattail leaves can be pelletized readily without any binders. The following table shows the calorific values of cattail leaves and rhizomes as compared with some common heat sources. Figure 15 shows the chopped, milled and pelletized samples of cattail shoots. The pellets were obtained without using any binders.

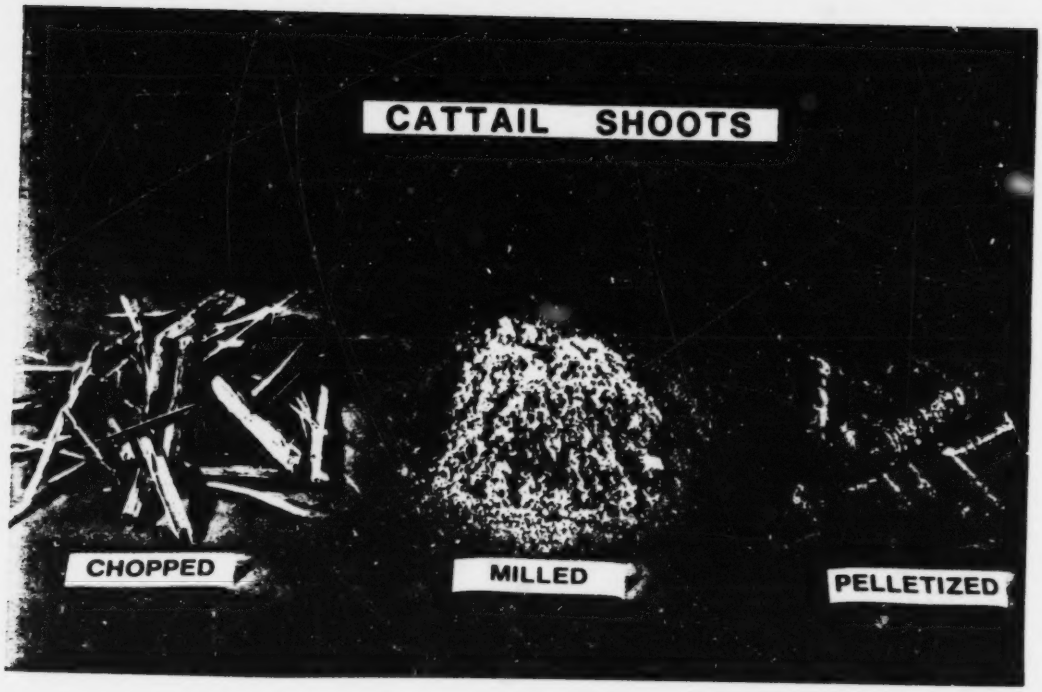


Figure 15. Cattail shoots can be pelletized without using binders, 1983.

TABLE 22

Calorific Values of Cattail Parts

SPECIES	BTU/lb	KJ/Kg
ALLIGATOR WEED	6245	14,550
WATER LILY	7127	16,606
COAL (LIGNITE)	6818	15,886
BIOGAS	16,363	38,126
SRC EXPERIMENTS		
CATTAIL LEAVES	8200	19,106
CATTAIL RHIZOMES	7700	17,941
BULRUSH LEAVES	7800	18,174
BULRUSH RHIZOMES	7750	18,058

Assuming an above-ground productivity of 20 tonnes per hectare, on a dry weight basis, approximately 380 GJ of energy can be produced from one hectare of cattail crop with a single annual harvest. Under Saskatchewan conditions, this is more than adequate to heat a 1,500 ft^2 home in northern Saskatchewan. It effectively provides a source for fossil fuel substitution. This estimate does not consider the harvesting of rhizomes and, therefore, maintains a perennial crop.

Cattails can provide a source of cheap protein for animals. The experiments conducted at the Saskatchewan Research Council have shown that the above-ground biomass harvested from freshwater wetlands and sewage treatment lagoons (shallow lagoons where cattails are grown in raw sewage as a method for providing tertiary treatment) contain appreciable quantities of crude protein and digestible organic matter. Their value as animal feed is comparable to treated straw and alfalfa as shown in the

following table.

TABLE 23

ANALYSIS OF THE HARVESTED BIOMASS FOR ITS VALUE AS ANIMAL FEED.

SAMPLE	¶ FEED PARAMETERS (%) dry weight basis						
	CRUDE PROTEIN	CRUDE FIBRE	DOM	ASH *	PHOS-PHORUS	CAL-CIUM	MOISTURE (as received)
CATTAIL							
08/09/76							
SAMPLE 1	17.2	31.8	55.2	10.8	0.6	0.8	86.0
SAMPLE 2	21.8	29.7	56.2	11.5	0.5	0.9	84.3
SAMPLE 3	17.4	N/D	52.9	N/D	0.5	N/D	88.6
27/09/76	19.1	31.0	61.4	12.9	0.5	1.1	74.1
04/07/76	21.3	28.4	59.3	13.7	0.7	0.9	88.5
ALFALFA	18 - 20		55 - 60				
STRAW	2.5-5.0		30 - 45				

*Ash values are not reliable as the samples were contaminated with dirt.

¶These values are for samples grown in nutrient rich media (sewage).

DOM = Digestible Organic Matter.

The residue obtained after fermentation will be quite high in its protein content and this should be considered while evaluating the economics of utilizing cattail as a substrate for ethanol production. The pay-back credits from the production of animal feed from the residue as a by-product make the cattail crop more relevant to the agricultural industry than its use without this recycling alternative.

Unfortunately, only limited data are available from a few studies on the rates saccharification for cellulose and hemicellulose components of cattail and the fermentation efficiencies that can be achieved. Studies by Ladisch and his co-workers at Purdue University have indicated that up to 17% of the total dry weight of cattail rhizomes can be extracted as sugars and other materials by a simple hot water wash. The residue after this wash contained about 25% hemicellulose, 34% cellulose and 15% lignin. Using 4% H_2SO_4 almost all of the hemicellulose was converted to sugars such as xylose and arabinose, and uronic and lactic acid components. The hydrolysis of hemicellulose was essentially quantitative. No degradation products such as furfurals were detected. Pretreatment of the residue from this process with a solvent CMCS, consisting of iron, tartrate, sodium hydroxide, water and a stabilizer, followed by enzyme hydrolysis yielded a 40% conversion to glucose, by weight. The residue contained 1% hemicellulose, 33% cellulose and 15% lignin. It was concluded that cattail rhizomes could yield between 0.6 and 0.8 kg sugar per kg of dry feedstock. The carbohydrates obtained from hydrolysis consisted of glucose, xylose, arabinose, starch, sucrose, fructose, uronic acids, carboxylic acids and other reducing sugars. Assuming a 50% conversion to ethanol, one kg of cattail feedstock can yield up to 0.4 kg ethanol if all sugars can be fermented.

A study conducted for the U.S. Department of Energy showed that over 50% of rhizome could be converted to ethanol, on a dry weight basis. This study projected a yield of over 320 litres of ethanol per tonne of dry biomass.

It appears from the U.S. experience that with appropriate agronomic

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management of cattail crops high yields reaching 40 tonnes of dry matter per hectare can be achieved with minimum fertilizer input in agriculturally marginal lands. For various production scenarios, the following tables (24 to 27) compare the potential ethanol yields from cattail with those from conventional feedstocks. If the existing hydrolysis and fermentation technologies were applied to the case of cattail, the ethanol production costs would be quite attractive.

The table giving the production and processing costs does not include land costs and capital costs which would be significantly low for cattail.

TABLE 24

ETHANOL YIELDS FROM CONVENTIONAL STARCH AND SUGAR BASED ENERGY CROPS

	Wheat	Corn	Sugarbeet	Sugarcane
Productivity	31.6 bu/A	101.2 bu/A	20.3 t/A	35.9 t/A
Potential Alcohol Conversion	2.6 USG/bu	2.8 USG/bu	24.3 USG/t	18.3 USG/t
Alcohol Yield, USG/A	82	283	493	656

bu = bushels
A = acre
t = tons
USG = U.S. gallons

It is envisaged that, with the expertise available at the Saskatchewan Research Council and the published data from laboratory studies on ethanol-from-cattail processes, a large scale plot study can be undertaken in northern Saskatchewan such as the Meadow Lake area to evaluate cattail as a viable energy crop. The on-going demonstration studies at

TABLE 25

PROJECTED ETHANOL YIELDS FROM CATTAIL BASED ON MODEST CONVERSION RATES

	Production Scenario			
Productivity, tonnes/ha	10	20	30	40
Fermentable biomass, @ 30% of total biomass tonnes/ha	3	6	9	12
Conversion to ethanol, @ 40%, tonnes/ha	1.2	2.4	3.6	4.8
Ethanol production, gallons/ha	333	668	1,001	1,335

Humboldt which use cattail marshes for treating sewage can be used to provide data on the effect of nutrients on the carbohydrate distribution in cattail. A possible scenario for a research and development project based on the utilization of cattail for energy and feed is shown in the schematic in Figure 16.

The cattail utilization concept has important implications for the environment in that it turns an environmental problem such as the treatment and disposal of sewage into an industrial opportunity. There are direct and indirect jobs created in the community from the large scale utilization of cattail. New small scale industries for producing and marketing pelletized fuel, feed and ethanol originating from such operations can stimulate the economic growth of northern communities.

The potential of cattail as an energy crop is compared with the existing energy crops such as wheat and corn in Table 27.

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The potential of cattail as an energy crop is compared with the existing energy crops such as wheat and corn in Table 27.

TABLE 26

ETHANOL PRODUCTION COSTS

FEEDSTOCK	LAND BASE	FEEDSTOCK	PROCESSING	TOTAL	EtOH YIELD L/t	REMARKS
		$/L of ethanol produced				
CORN	A	0.28	0.44	0.69	420	P
SUGARCANE	A	0.28 - 0.36	0.16	0.44 - 0.52	77	P
SUGARBEET	A	0.27 - 0.43	0.16	0.43 - 0.59	102	P
WOOD	W	0.12 - 0.20	0.35	0.47 - 0.55	200-256	S
TREMBLING ASPEN	F	0.12	0.28	0.40	257	S
WHEAT	A	0.15	0.18-0.27	0.33 - 0.42	446	P
CATTAIL	W	0.20	0.28#	0.48	351*	N

A = Agricultural Land; F = Forest Land; W = Wetland, Peatland, Saline & Marginal Land.

P = Premium Land Prices; S = Site-specific Costs; N = Negligible or Zero Land Costs.

Costs for acid hydrolysis and fermentation; Biomass harvested for maximum starch and sugars.

* Based on a conservative estimate of conversion and fermentation rates; 70% conversion to fermentable materials, 40% fermentation efficiency.

¶ Total costs do not include land costs and capital costs.

EtOH yield L/t = Ethanol yield in Litres per tonne of biomass

TABLE 27

A COMPARISON OF CATTAIL WITH OTHER ENERGY CROPS

Parameter	Cattail	Wheat	Corn
Land Base	Large Wetlands, Non-agricultural, moderately saline lands.	Restricted Fertile to moderately fertile agricultural lands.	Restricted Similar to wheat
Land Cost	None	High	High
Fertilization	Mostly none. Some long term need	Annual	Annual
Weeds and Pests	None	Yes	Yes
Preparation	None except while planting	Annual land preparation required	Annual
Harvesting	Development needed	Well established	Well established
Collection	Some adaptation needed	Well established	Well established
Dewatering & Drying	Development needed	Well established	Well established
Hydrolysis & Fermentation	Technology available. Research and development needed to optimize ethanol yields from structure specific feedstocks.		

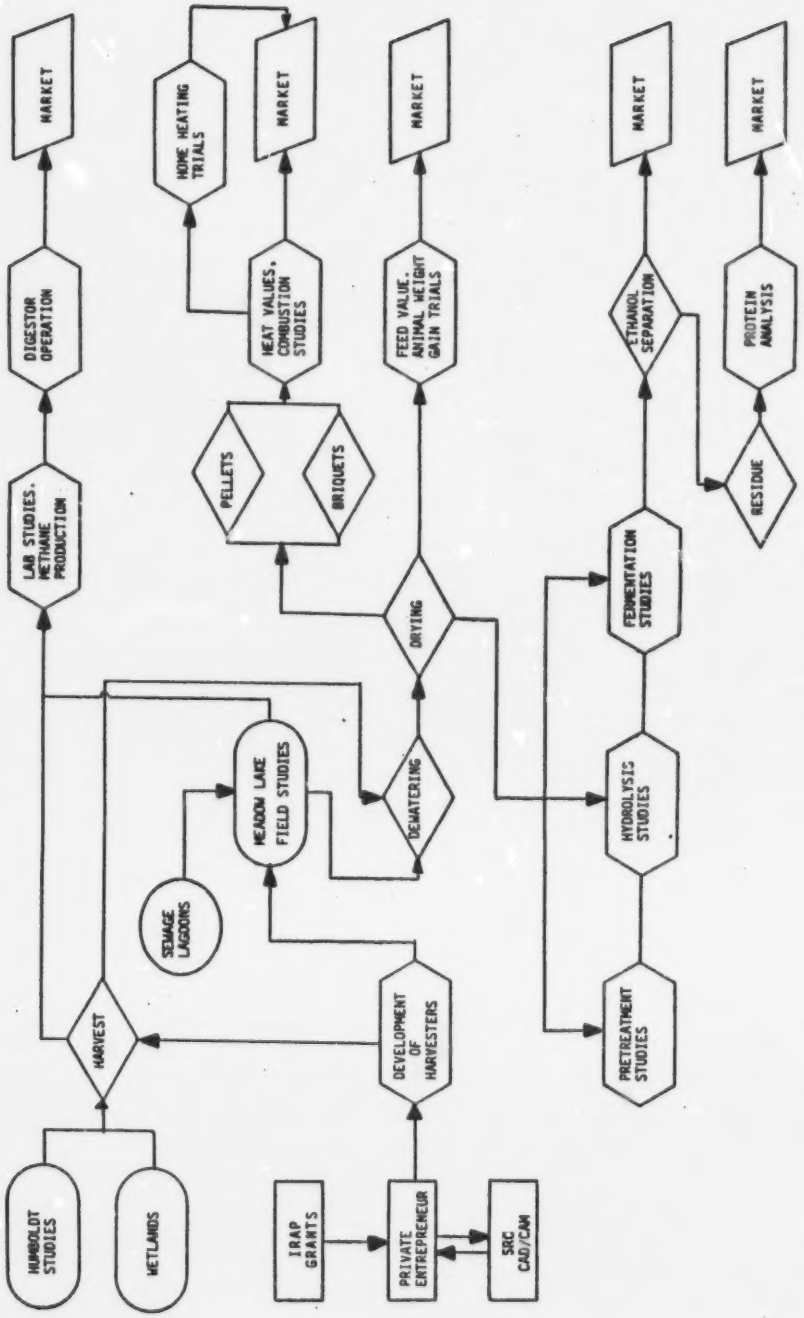

FIG.16 SYSTEM SCHEMATIC SHOWING THE DEVELOPMENT OF CATTAIL AS A VIABLE ENERGY AND FEED CROP

CONCLUSIONS

1. The growing energy demand in Canada, particularly from those sources based on renewable resources will necessitate a closer examination of alternate biomass sources for providing energy.
2. There is a need to avoid food-feed-energy conflicts which will undoubtedly arise if conventional crops are used for energy production.
3. Valuable agricultural lands form only about 13% of the total land area, of which about 60% is suitable for field crops and 40% is suit-suitable for pasture.
4. Energy plantations based on utilizing agriculturally unuseable lands, moderately saline lands, and the vast areas of wetlands in Canada offer the attractive prospect of developing an energy base with very low production costs.
5. Potential land base available for wetland energy crops is enormous, between 780,000 km^2 and 5,3000,000 km^2. Even if a small fraction of this is utilized to develop managed cultivation of cattail crops, it would generate significant quantities of biomass on an annual basis.
6. As a ubiquitous and perennial aquatic plant cattail stands out clearly as a potential energy crop in the Canadian context. Its high biomass yields, ability to survive and grow in poor soil and water environments, and its impressive carbohydrate spectrum for an aquatic plant are some of its merits which should be examined in detail.
    - The annual productivity in managed stands range anywhere between 15 and 40 tonnes of dry matter per hectare, depending upon the density and method of cultivation.

- It has a high photosynthetic efficiency ranging from 3.8 to 13.6% and a very efficient C_3- photosynthetic pathway.
- The leaf-area-index, an indicator of energy capture efficiency, reaches up to 18.2.
- Cattail can tolerate salinity levels of up to 10 milli mho/cm, and wide variations in pH from about 5.0 to about 11.0.
- The plant has a major carbohydrate storage and biomass production in the rhizomes. Up to 70% of the total plant productivity can be found below ground.

7. The carbohydrate distribution in the plant varies somewhat as follows:

	Cellulose	Hemicellulose	Lignin
Leaves	30 to 35%	19 to 37%	10 to 15%
Rhizomes	10 to 40%	About 25%	Low

	Starch	Sugars	Fermentable Material
Leaves	-	Up to 4%	Over 11%
Rhizomes	Over 35%	About 25%	Over 40%

The starch from cattail consists mostly of amylopectin, and upon acid hydrolysis yields mostly glucose.

The pentosans which constitute most of the hemicellulose in cattail are between 7 and 17% of the total hemicellulose.

The starch and sugars in the rhizomes by the end of September exceed the cellulose content by a factor of 1.5.

The starch in the rhizomes reaches a maximum during the fall; the sugars in the leaves peak during August.

8. Field trials in the U.S. have shown that cattails can be harvested

using either special harvesters such as the Seiga Harvesters manufactured in Denmark for harvesting reeds and rushes or simple adaptations of swathers and potato pickers. Seiga harvesters can negotiate steep slopes, travel on ice and water, and exert very little pressure on ground. Their tires exert approximately 40 g/cm^2 pressure while empty and about 100 g/cm^2 while carrying a load of 3 tonnes. Developmental work to provide a harvester, which can operate in terrains typical of aquatic habitats is urgently needed.

9. There are three important advantages for cattail as an energy crop, which will significantly enhance the economics of ethanol production.

a) Material availability

Vast land resources including wetlands, non-agricultural lands, moderately saline lands and peatlands are available as potential energy crop areas where cattail cultivation can be initiated.

Cattail crops do not require annual fertilizer and herbicide applications. However, in the long term operation of land for energy crop cultivation it may become necessary to improve the nutrient availability either through occassional fertilizer application or by incorporating sewage, partly treated or untreated, from a nearby community as a source of nutrients.

There are no pests or diseases affecting the cattail crop.

Capital investment is low or minimal compared to the conventional energy crops.

Biomass can be readily pelletized without any binders if long term storage or long transportation is required.

b) Carbohydrate composition

The leaves contain cellulose and hemicellulose which yield hexoses and pentoses for fermentation after acid or enzyme hydrolysis.

Total non-structural carbohydrates account for more than 50% of the total rhizome weight and with simple pretreatment and hydrolysis more than 60% of the total biomass can be converted to fermentable sugars.

The reserve carbohydrates in the rhizome increase during the later part of the growing season and reach a maximum during the fall.

c) Economic impact of cattail utilization

Cattail leaves can be harvested, pelletized and used as a fuel for combustion in modified furnaces and straw burners. This will provide home heating, an alternative for fossil fuels in remote communities. The calorific value of cattail at about 19 GJ/t compares favourably with the heating value of 15.9 GJ/t obtainable from lignite coal. Cattail leaves harvested from one hectare can produce enough energy to heat a 1,500 ft^2 home in Saskatchewan throughout the year.

Cattails can also provide a cheap source of protein for animals. Plants grown in nutrient-rich media contain from 17.0 to 22.0% crude protein, and from 53.0 to 59.0% digestible organic matter.

The residue obtained after fermentation will contain higher amounts of protein and can offer better economic pay-back credits to the energy costs.

10. A systematic and detailed study of the nature of the carbohydrates in cattail, their variation with the growing season and the factors

affecting their translocation, synthesis and hydrolysis within the plant system should be conducted to evaluate the full potential of the feedstock. Reliable data are not available to determine the optimum methods of saccharification for the aerial and below-ground portions of the plant and the most efficient fermentation process to obtain best yields of ethanol. No data exist on the protein value of the residue after fermentation. Appropriate pre-treatment techniques have not been developed specific to the cattail biomass. This is, understandably, due to the lack of research effort to identify potential aquatic plant species for energy production. Available information from laboratory studies does, however, show that cattail has potential as a viable energy crop.

11. Appropriate agronomic management of cattail can produce multiple, above-ground harvests and a single high biomass production from the rhizomes in the fall. There is a good deal of information to show that domestic sewage, either untreated or partly treated, can serve as a cheap nutrient source in place of chemical fertilizers. Such a scheme would also help to turn an environmental problem (sewage disposal) into an industrial opportunity.

12. The economics of ethanol production from cattail at this time, in absence of any cost data specific to cattail, can only be surmised from an extrapolation of related data available for conventional grain energy crops. The cattail crop can produce two distinct types of feedstocks; the starch and sugars from the rhizomes and cellulose and hemicellulose from the leaves. Multiple harvests of leaves and a complete harvest of the plant in the fall can bring economically

advantageous factors in the cattail operation. Pre-treatment of leaves and probably of rhizomes also, developed specifically to deal with the specific nature of the carbohydrates in cattail followed by acid hydrolysis will yield fermentable sugars impressive for an aquatic plant.

The following summarizes the ethanol production costs for cattail feedstock based on the extrapolation of the available data.

1. Productivity Scenarios:

Productivities range from a low of 10 tonnes per hectare to a high of 40 tonnes per hectare, on a dry weight basis. Higher yields have been reported from India and Czechosolovakia. Agronomic management can increase and maintain high yields under various operating conditions.

The feedstock cost is less than $0.20 per litre of ethanol produced. There are important factors such as multiple annual harvests, improved harvesting and collection operations, marginal fertilizer needs and almost zero land costs which can contribute to lower feedstocks costs.

2. Fermentable Biomass Production:

Approximately 35 to 70% of the total biomass can be converted into fermentable material depending upon the rhizome production and the nutrient status. Timing the harvest to synchronize with the peak carbohydrate storage in the rhizomes will enhance the efficiency of the conversion process.

Cattail produces essentially two types of feedstocks, mainly cellulose and hemicellulose from the leaves and starch and sugars

from the rhizomes. The feedstock can be processed using acid hydrolysis and fermentation with some pretreatment. The processing cost has been estimated to be less than $0.28 per litre of ethanol produced. Further laboratory investigations will undoubtedly reduce this cost.

3. Ethanol Costs:

Further research and development work on cattail as a substrate is expected to substantially reduce the cost of ethanol production. At the present time, assuming that conventional cellulose and starch hydrolysis and fermentation techniques are applicable to the cattail feedstock without additional pretreatment, the cost of ethanol from cattail would be less than $0.48 per litre. Pay-back credits from the utilization of the residue after fermentation as an animal feed will make the economics more attractive.

13. Utilization of cattail as a combustible fuel in the form of pellets, briquets or bales for home heating and agricultural dryer operation (for drying grain) merits attention. The following table compares the calorific value (heating value) of cattail parts with the values for natural gas and lignite coal.

Source	Heating Value (GJ/t)
Coal (lignite)	15.9
Biogas	38.1
Cattail leaves	19.1
Catail rhizomes	17.9

RECOMMENDATIONS FOR FUTURE RESEARCH PROGRAMS

1. Large scale plot studies should be conducted to determine the following.

   a) Maximum productivities which can be achieved under optimum growing conditions.

   b) Variability in the maximum productivities due to the nature of the growing media, such as

      . salinity levels

      . nutrient status

      . water conditions

   c) Effect of climatic conditions such as the length of the growing season and the temperature regimes on the productivities.

2. Evaluate the feasibility of multiple above-ground harvests and one complete harvest per growing season for producing high material yields.
3. Study the variability of carbohydrate spectrum during the growing season and establish optimum harvesting schedules to produce maximum carbohydrate yields.
4. Study the effect of fertilization on the nature and magnitude of carbohydrates in the cattail crop.
5. Carry out pretreatment studies to improve the conversion of cellulose and hemicellulose fractions into fermentable material.
6. Evaluate acid and enzyme hydrolysis for producing fermentable sugars from the plant and establish the most cost effective pathways.
7. Conduct laboratory scale fermentation trials and develop cost and process parameters for pilot scale operations.
8. Evaluate the availability of cattail harvesters in the market and

conduct or encourage developmental projects to design and test harvesting equipment to suit Canadian conditions.

9. Investigate the utilization of protein residue after fermentation for animal feed and the use of pelletized cattail biomass for home heating. Determine cost-benefit factors.
10. Develop information on the potential for creating jobs and industries in communities where this aquatic resource can be exploited, as a function of the scale of operation.

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